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DESIGN OF A NATURAL RESOURCES INVENTORY AND INFORMATION SYSTEM FOR COSTA RICA:

THE PILOT PROJECT REPORT

Prepared For:

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Regional Operations Division, Latin America
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1.0 EXECUTIVE SUMMARY

In its 1977 Costa Rica Agricultural Sector Assessment Review, the USAID Mission to Costa Rica noted: "The most critical problem facing the Ag Sector is deforestation and the attendant destruction of soil and water resources. If the process is not halted there will be little resource base left upon which to build future agricultural development...information gathering and analysis to provide policy makers with complete current information is essential" if this problem is to be adequately addressed (1).

Accelerating rates of land use change and their associated impact on the environment has prompted the Government of Costa Rica to initiate new land management policies. Current pressures on natural resources are outpacing the ability of government institutions to adapt rapidly enough to prevent or curtail the problems. Unfortunately, in Costa Rica, as in many tropical countries, the natural resource information base is incomplete, often several years out of date, and may be of questionable accuracy and reliability. This is a direct result of limited budgets for resource surveys and a scarcity of trained professional personnel to organize and conduct a comprehensive natural resources inventory. While for these reasons very little resources inventory work has been done in Costa Rica in the last 10 years, the Government of Costa Rica recognizes that one of their most urgent needs is for a nationwide inventory to define what they actually have and what they are losing (2).

In a letter to the USAID Mission Director in January, 1977, the Minister of Agriculture in Costa Rica commented on these problems, noting that to complete an inventory of forest lands alone would require a budget of $20 million and 25 years of time using traditional methods, and requested USAID assistance. A multi-phase program was subsequently undertaken to design and develop an operational natural resources inventory and information system in and for Costa Rica, incorporating recent advances in resources survey and analysis technology. Resources

Development Associates of Los Altos, California, has served as the principal contractor on this program.

The first phase "Demonstration Project" investigated alternative ground, aircraft and satellite data collection systems and analysis techniques and their utility in Costa Rica. The results of this phase formed the base for the second phase "Pilot Project" which developed and tested an operational system for the cost-effective inventory, analysis, storage and retrieval of land use and renewable resources data in Costa Rica. This system was tested on a cross-sectional area representing more than 20% of the entire country to define and solve, by encountering them, the operational problems involved in performing a nationwide survey (Figure 1-1). The project was to develop information of sufficient detail, accuracy and reliability to support government management and policy decisions in the areas of environmental protection, urban planning, regional resources management and economic development.

Remote sensing data obtained from the Landsat satellite and color infrared photography provided a current inventory of land cover for the pilot project study area. The inventory was not only limited to data collection from remote sensors, but also included existing ancillary and terrain data (soils, drainage, slope, etc.) to allow a more comprehensive evaluation of land resource attributes. The inventory, data processing and map preparation utilized some of the most advanced techniques available, however, much care was taken to prepare a resources information system which would be responsive to the GOCR's needs while being compatible with their capabilities to maintain it.

With this goal in mind, all resource data were compiled at common (national topography) map scales. Also, to achieve maximum durability and use of the inventory data, full production line methods were followed in the preparation of thematic maps at 1:200,000 and 1:50,000 scales. Two 1:200,000 maps and eight 1:50,000 scale thematic maps sets were prepared. Each map

1:200,000 Scale Maps:

A San Jose

B Limon*

1:50,000 Scale Maps:

1 Naranjo

2 Barba

3 Golfo

4 Barranca

5 Rio Grande

6 Abra

7 Tarcoles

8 Matina

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* Includes a visual Landsat land cover classification only.

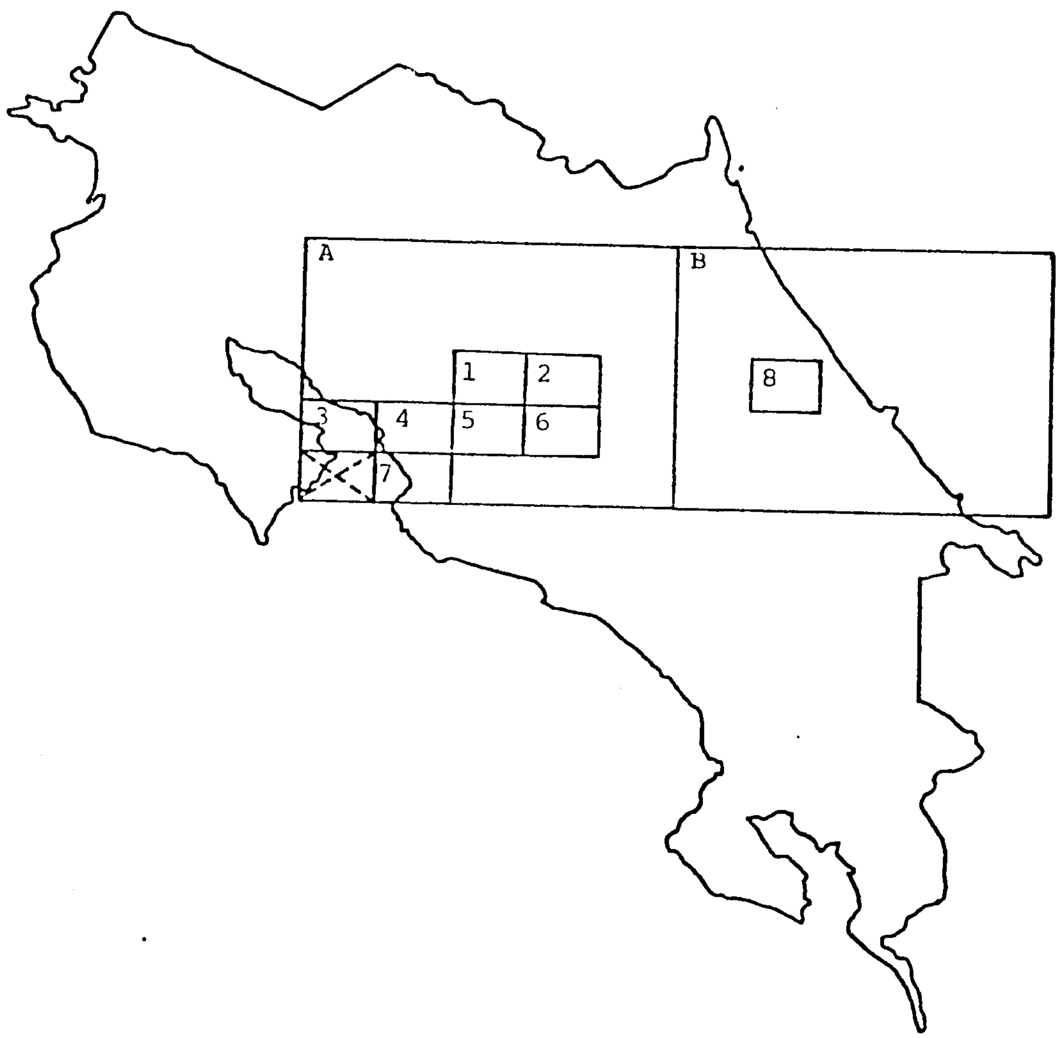


Figure 1-1: THE PILOT PROJECT STUDY AREA

"theme" (in the form of a clear plastic overlay) displays the spatial distribution of resource attributes to be viewed in combination with the topographic map base and other resource themes.

Thematic maps were used in the development of a biophysical classification and preparation of a "land management" map intended to yield location specific information relating to the capability and suitability of the land to support particular uses. This map, with further refinements, could be valuable in supporting land use planning guidelines urgently needed in Costa Rica.

Technology transfer to the GOCR personnel was an integral part of the pilot project. Six professionals representing resource management and planning agencies within the GOCR participated in an intensive U.S. training program designed to improve their comprehension and develop their skills in the application of remote sensing techniques to natural resources inventory. The GOCR professionals participated in all phases of the data collection, analysis and map preparation for the pilot project.

The major analyses and techniques applied to the inventory data included: 1) land cover/land use area measurements and data aggregation for topographic maps and selected administrative units; 2) evaluation of Landsat land cover classification accuracy; 3) potential erosion hazard sites and areas prime for reforestation; 4) land use change detection and monitoring of agricultural to urban land conversion and deforestation; and, 5) cost-effectiveness analysis of remote sensing data for resources survey with implications for the national inventory program.

This study has further confirmed and defined the magnitude of the resources and environmental problem in Costa Rica. Figure 1-2 shows an area in western Costa Rica near the Gulf of Nicoya. Forest cover in this area decreased nearly 77% between 1944 and 1975 according to a Landsat / aerial photographic comparative study. Results of a more detailed study of a portion of this area using aerial photography are presented in Figure 1-3. This confirms a nearly one-to-one relationship between the decrease in forest lands and increase in grazing lands.

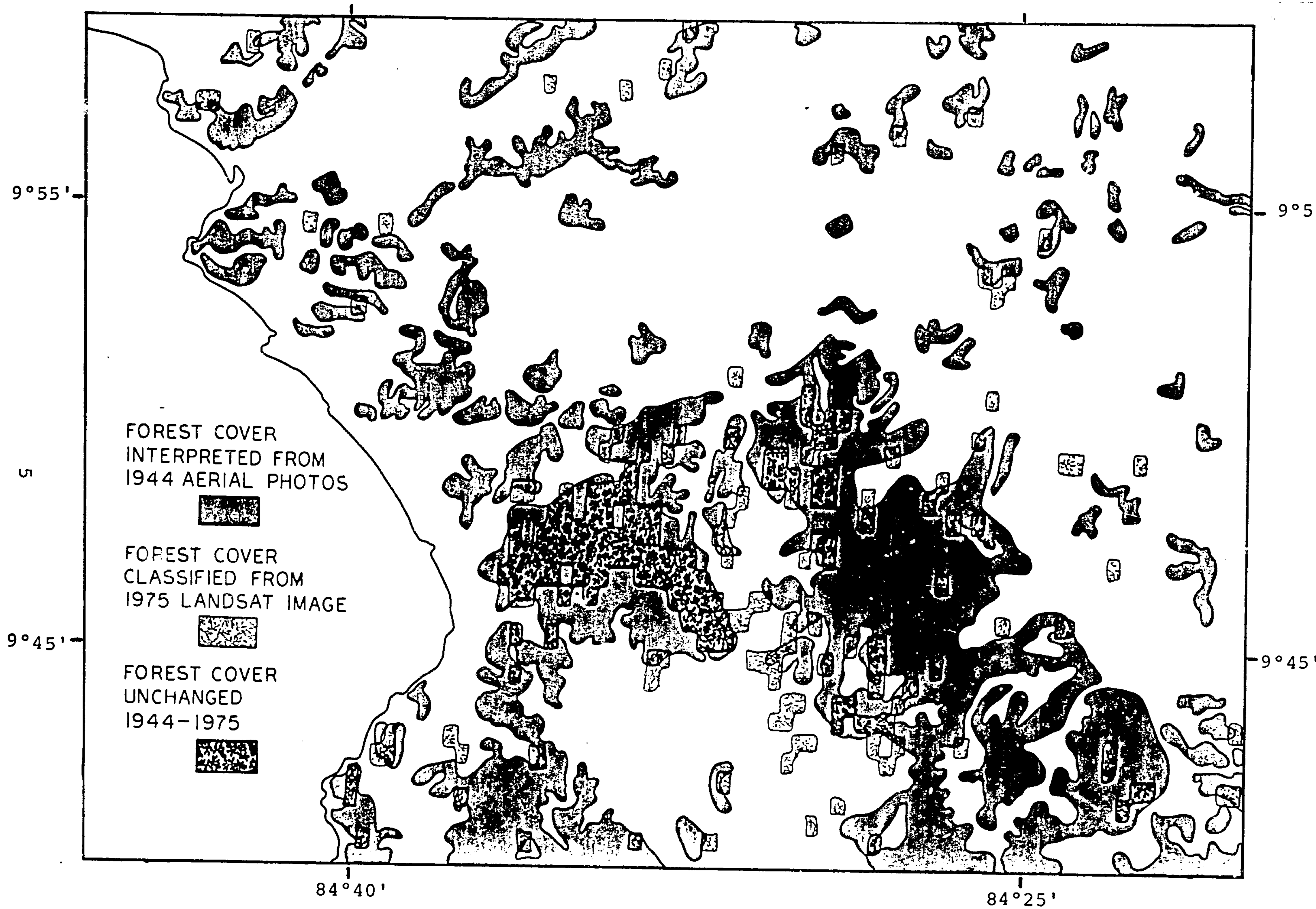
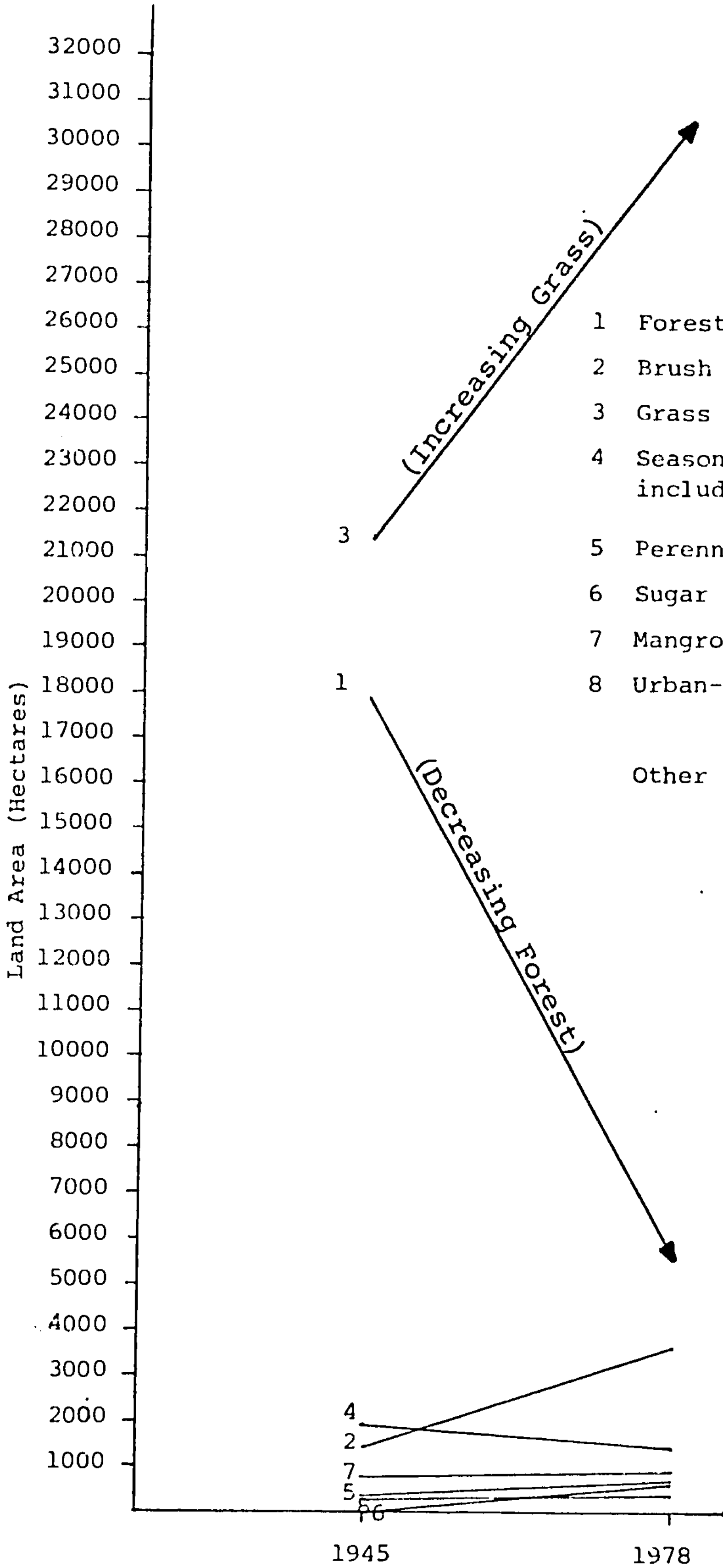


Figure 5-16: FOREST AREA COVERAGE AS DERIVED FROM 1944 PHOTO INTERPRETATION AND 1975 LANDSAT COMPUTER-ASSISTED CLASSIFICATION



		1945 Ha.	1978 Ha.	% Chang of Total Land Area
1	Forest	17,881	5,640	-27.
2	Brush with Trees	1,449	3,654	+ 4.
3	Grass Dominant	21,417	30,508	+20.
4	Seasonal Agriculture including Rice	1,947	1,452	- 1.
5	Perennial Agriculture	417	754	+ .7
6	Sugar Cane	0	672	+ 1.5
7	Mangrove	764	930	+ .3
8	Urban-Residential	323	404	+ .1
		44,198	44,014	
	Other Land	804	990	
		45,004	45,004	

Figure 1-3: BARRANCA LAND COVER ESTIMATE OF CHANGE FROM 1945 TO 1978

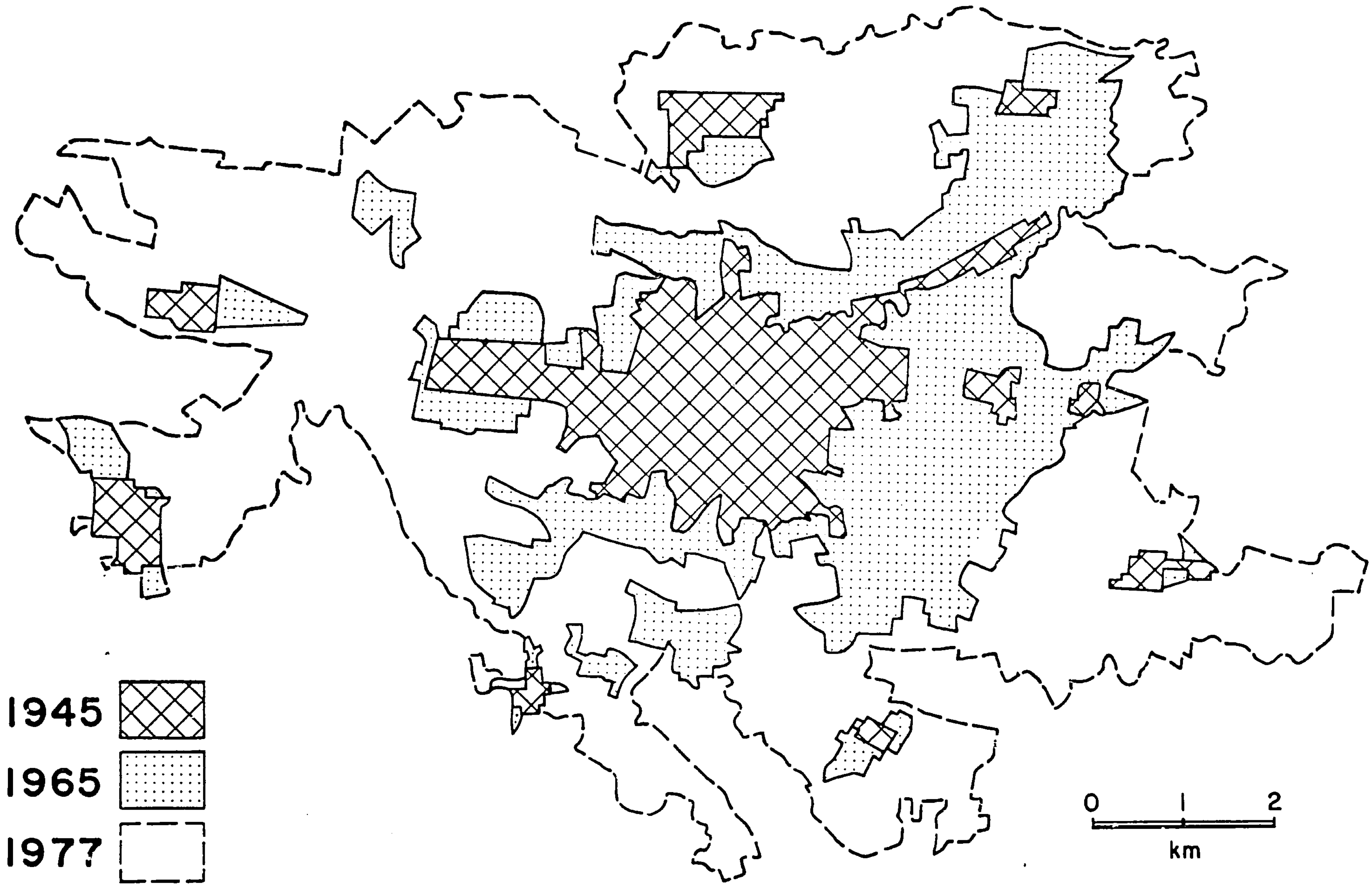
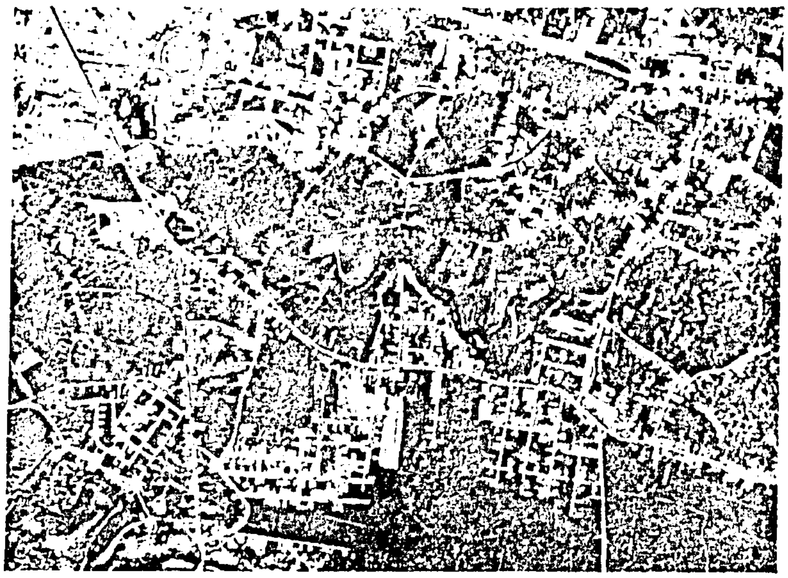
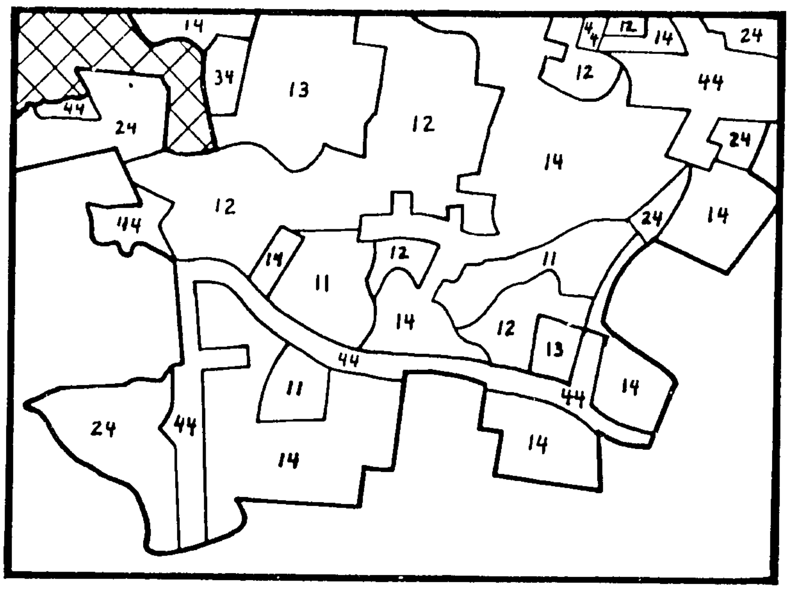


Figure 1-4 : EXPANSION OF THE URBANIZED AREA
San Jose, Costa Rica

1945



1965



1:25000

1945 to 1965 CONVERSION

LAND USE STAGE CONTINUUM*

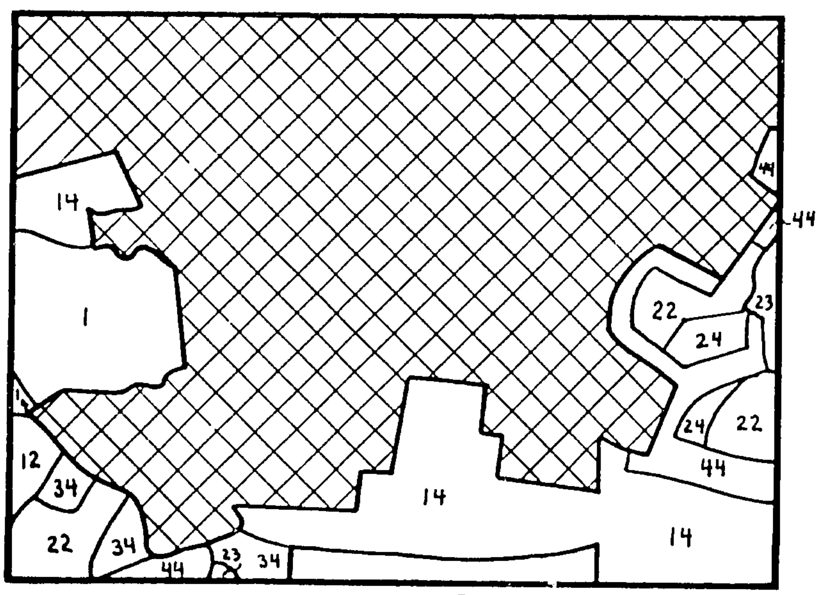
1. ACTIVE AGRICULTURE
2. ABANDONED AGRICULTURE
3. TRANSITION TO URBAN
4. URBAN

*Each conversion polygon contains two numerals, indicating the initial and subsequent stages.

Figure 1-5

1965

1977



1:25 000

1965 to 1977 CONVERSION

LAND USE STAGE CONTINUUM*

1. ACTIVE AGRICULTURE
2. ABANDONED AGRICULTURE
3. TRANSITION TO URBAN
4. URBAN

*Each conversion polygon contains two numerals, indicating the initial and subsequent stages.

Figure 1-6

Similar changes have taken place in the agriculturally-important Meseta Central region as land has transitioned from agriculture to urban uses. Figure 1-4 outlines the expansion of the urbanized area of San Jose between 1945 and 1977. Details of this transition for a sample area are shown in Figures 1-5 and 1-6.

In summary, this project has developed and demonstrated operational procedures for a natural resources inventory and information system that meets the current requirements of the Government of Costa Rica and can be both implemented and maintained by Costa Rican professional personnel. This system should now be implemented on a nationwide basis.

As a first step, a multi-disciplinary, multi-agency project team should be formed to complete a resources inventory of the country at mapping scales of 1:50,000 and 1:200,000, utilizing a combination of CIR photography and Landsat digital data. A single organization within the GOCR should be given clear administrative responsibility for this project. This entire project can be completed in less than three years at a total cost of less than $1 million.

This inventory should be combined with existing resources data in map and tabular form into a manual geo-based information system. This system should be maintained and periodically updated to monitor changes in environmental quality, the condition and the extent of the natural resources base. Combined with standard forecasting techniques, the system would assess the impact of these changes as a guide to determination of public policy and implementation of that policy. Land cover/land use can be updated for the entire country at five-year intervals using aerial photography or at two-year intervals using Landsat data.

A continuing training program should be established in Costa Rica to familiarize resources managers and data users with the techniques and application of remote sensing. A research program should similarly be initiated to further improve existing techniques of tropical resources inventory and environmental monitoring.

2.0 INTRODUCTION

This section provides an overview of the current resource problems facing Costa Rica. The status of the program designed to address these problems is presented together with its developmental history.

2.1 Environmental and Natural Resource Problems

Costa Rica is experiencing a period of rapid economic development which is having a profound effect on the country's forest, agricultural and urban land base.

The forest land base is undergoing a steady decline as an alarming amount of forest is being cleared, especially on steep slopes, to accomodate more agricultural and grazing uses. In some cases, the short-term benefits of providing more land for marginally productive agricultural and grazing uses may be far outweighed by the long-term consequences arising from the loss of virgin forest and the accompanying environmental degradation which results.

In Costa Rica, as in many other countries throughout the world, the most intensive urbanization often occurs on land that is highly productive for agricultural uses. The continuing expansion of urbanization into agricultural land, particularly in the Meseta Central, could have a significant impact on the economy because some of Costa Rica's most important agricultural exports (e.g., coffee and sugar) as well as much of the internally-consumed foodstuffs are produced here.

Although expansion itself is consistent with national goals of increased production and economic development, uncontrolled and unplanned development is often counter to the wise use of land.

2.1.1 Deforestation

"The world is being confronted by an extremely serious problem with immediate and long-range socio-economic and ecological consequences as the result of the accelerating loss of forest and vegetative cover in the humid and semi-arid lands within or near tropical latitudes..." (3) This was the major conclusion expressed by the U. S. Strategy Conference on Tropical Deforestation sponsored by the U. S. Department of State and the U. S. Agency for International Development in June 1978. The fact that a conference by this title brought many experts together to share their views and concerns about the nature and impact of deforestation worldwide shows that Costa Rica has current natural resource problems common to many tropical countries.

As noted at this conference, Latin America is believed to possess approximately 550 million hectares or one-fourth of the total closed forest area in the lesser developed countries (LDCs) as of 1978. If current trends continue to the year 2000, the projected forest area in Latin America will decrease to approximately 329 million hectares, or a reduction of 40%. Most of the remaining forests by the year 2000 will be found only in inaccessible areas.

Reflecting the Latin American trend, Costa Rica is experiencing an alarming rate of deforestation. The current estimated timber removal in Costa Rica is between 50,000 and 60,000 hectares per year while the estimated reforestation rate is only 1,000 hectares per year (4). The Direccion General Forestal (DGF) estimates that the timber from 10,000 hectares may be worth roughly about 300 million Colones at the mill (5). Given this estimate and a 60,000 hectare/year rate of cut, then the gross value of timber cut each year in Costa Rica would be 1800 million Colones, or more than $210 million per year. No data are currently available to indicate what percentage of this cut is on national as opposed to private lands.

Forest clearing in Costa Rica usually begins on or near ridgetops and progresses down slope (Photo 2-1). In some areas, notably Guanacaste and Puntarenas Provinces, this clearing has been so extensive that very little primary forest remains.

Many watersheds have been totally denuded of forest cover which has resulted in extensive erosion and subsequent sedimentation to rivers and reservoirs. Excessive grazing has also exposed soil which will rapidly erode (Photo 2-2). The Soils Department of the Ministerio de Agricultura y Ganaderia (MAG) has identified major topsoil losses from steep slopes cleared of primary forest. As a result of vegetation and topsoil losses, infiltration and water storage capacity is greatly reduced in deforested watersheds. The risk of uncontrolled flooding of rural settlements and low-lying agricultural areas is increased. The availability of water for existing and projected agricultural irrigation and water supply projects is significantly reduced.

Forests are also important to the local economy as a source of raw materials used in housing construction and specialty products for the tourist industry. They provide firewood for heating and cooking in many rural areas. The ramifications of extensive deforestation are so all-encompassing that virtually every segment of the Costa Rican society either already is or will be affected.

Recent research on the effects of deforestation on carbon dioxide levels in the atmosphere has indicated that widespread deforestation may cause serious alteration of regional climate and have far-reaching global effects (6). Although the research is inconclusive, the specter of prolonged droughts in deforested regions and the creation of biological deserts in formerly productive areas are issues of major international concern.

Photo 2-1: Current forest clearing near the mouth of the Tarcoles River.

Photo 2-2: Severe gully erosion caused by forest clearing, road construction and overgrazing.

2.1.2 Agricultural-Urban Land Conversion

Another trend in land use conversion having major impact is exemplified within the more densely populated and valuable agricultural region of the Meseta or Valle Central. The capital city of San Jose has grown rapidly in recent years both in population (from 145,000 in 1945 to 487,842 in 1973) and in areal extent (7). Surrounding satellite cities of San Jose are experiencing a similar magnitude of growth. Much of the agricultural land which has recently been converted to urban uses, or neglected in anticipation of conversion, has historically been devoted to the production of coffee, an export commodity that provides Costa Rica with significant amounts of foreign exchange. The conversion of this land to high value commercial-industrial development may be defensible as necessary to the country's economic growth but the placement on much of this land of discontiguous housing developments, especially those built at some distance from the contiguously built-up area, poses the dual problem of removing valuable land from production while requiring the provision of often inordinately expensive urban services.

Yet another problem is that the extended perimeter of urbanization shows indications of engulfing former distinctive satellite communities once separated from the main city by an agricultural "green belt". Communities such as Tibas and Moravia are already in the process of becoming only neighborhoods of the expanded city of San Jose. Trend projection suggests that Heredia and Alajuela will follow a similar course. Large areas of undeveloped land in this region are surrounded by developed land as seen in the small-scale color infrared photograph of the city and environs, (Photo 2-3), suggesting that these areas as well are candidates for urbanization.

The extremely rapid areal expansion of cities has presented a challenge to planners on how best to monitor and evaluate this unprecedented, rural-to-urban conversion of land. In addition to the many inherent societal, political, and economic problems

incurred by urban growth, there is simply the problem of how to acquire and keep current map information on urbanization to facilitate analysis, evaluation, and policy making.

The problem of effectively monitoring urbanization is universal. Even in older and well-developed countries, national censuses (the most reliable indicator of growth) are acquired too infrequently to provide information of sufficient currency for governmental action. Planning for revenue dispersal, housing, transportation, and utilities are but a few of the needs for up-to-date information.

2.2 Project Background

The Pilot Project in Costa Rica, initiated in January 1978, was preceded by earlier definition studies and a "Phase I" Demonstration Project. These have been described in detail in several reports (8-12). This section presents a brief summary of the results, conclusions and recommendations of these earlier studies together with an outline of the goals and objectives of the Pilot Project itself.

2.2.1 Demonstration Project - Phase I

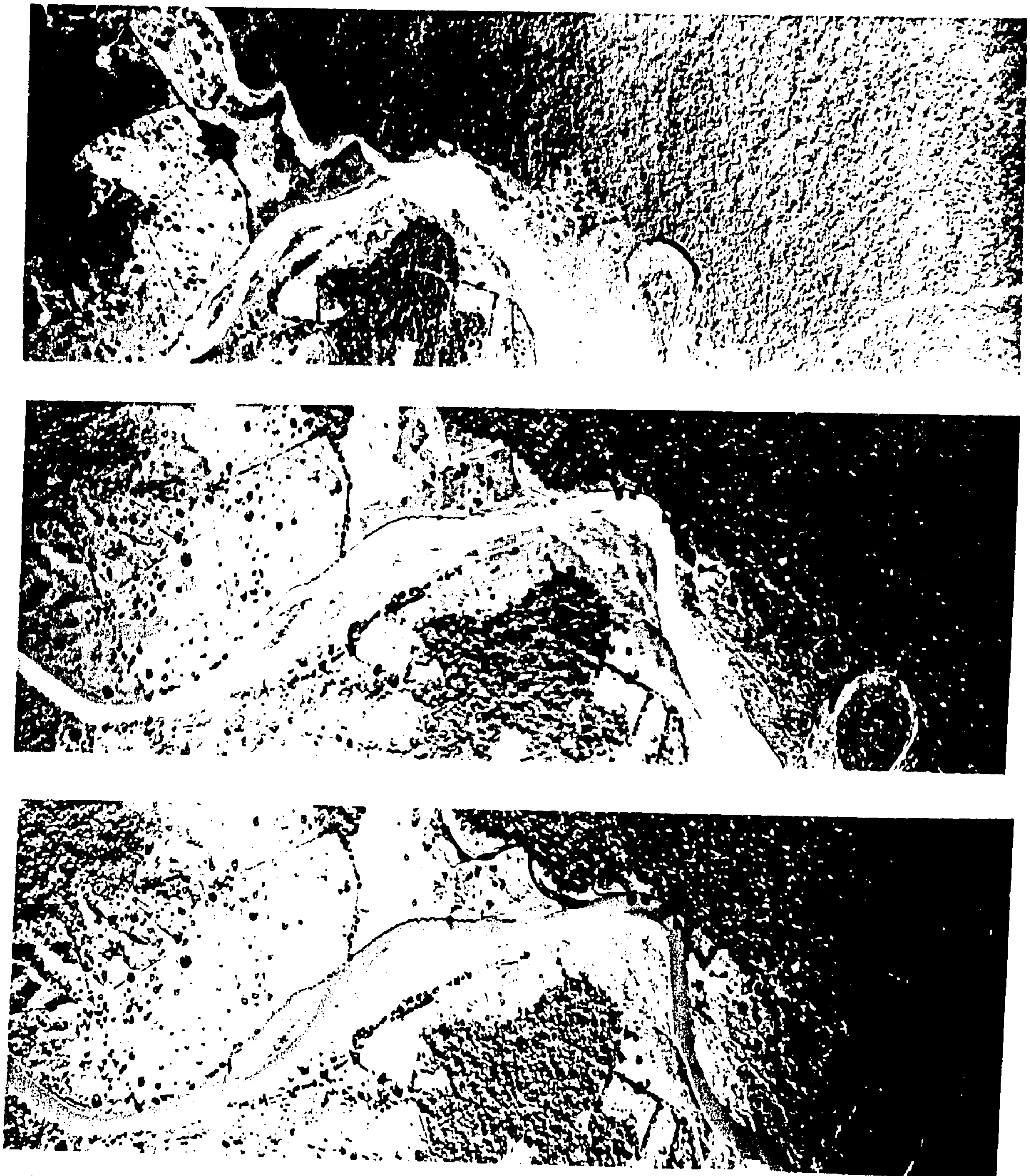
In 1977, Resources Develoment Associates (RDA) was asked by USAID and the Government of Costa Rica to investigate possible applications of remote sensing techniques for natural resources survey and assessment in Costa Rica. Information derived from this initial investigation contributed to the formulation of a three-phased natural resources inventory program.

The "Demonstration Project", forerunner of the remote sensing Pilot Project in Costa Rica, was originally designed as a forest land program, aimed at providing more and better information regarding the extent and ramifications of deforestation in the country, and rates of change in critical areas. The scope of the project was subsequently broadened to include other aspects of land cover and land use change. As finally developed, a major thrust of the Demonstration Project was to outline a resources information system, utilizing the most appropriate remote sensing technology for resources survey and monitoring purposes, that could produce timely and reliable information on which to base resources management decisions and policy.

2.2.1.1 Results

An aircraft and satellite remote sensing data collection and analysis program was completed to determine the most cost-effective approach to the development of a resources information base for Costa Rica. Manual interpretation of black and white panchromatic, color, and color infrared aircraft photography (Photo 2-4), as well as visual and digital products generated from Landsat satellite date (Photo 2-5), were compared with regard to collection, timing, cost, and accuracy. Information needs were assessed in detail for each of the areas of primary interest: forest, urban land use, range, and agriculture.

Considerable care was given to the develoment of a land cover classification system which could profit from related experience gained in the United States and elsewhere, yet be responsive to the unique characteristics of the Costa Rican landscape. A set of land use/land cover maps was prepared. Landsat digital data were compared and evaluated against the photographic data base. The results of this project provided the necessary information for decisions concerning the selection of an optimum combination of data collection and analysis techniques as well as the type of map products that might be used in a pilot study of land use and land change in Costa Rica.

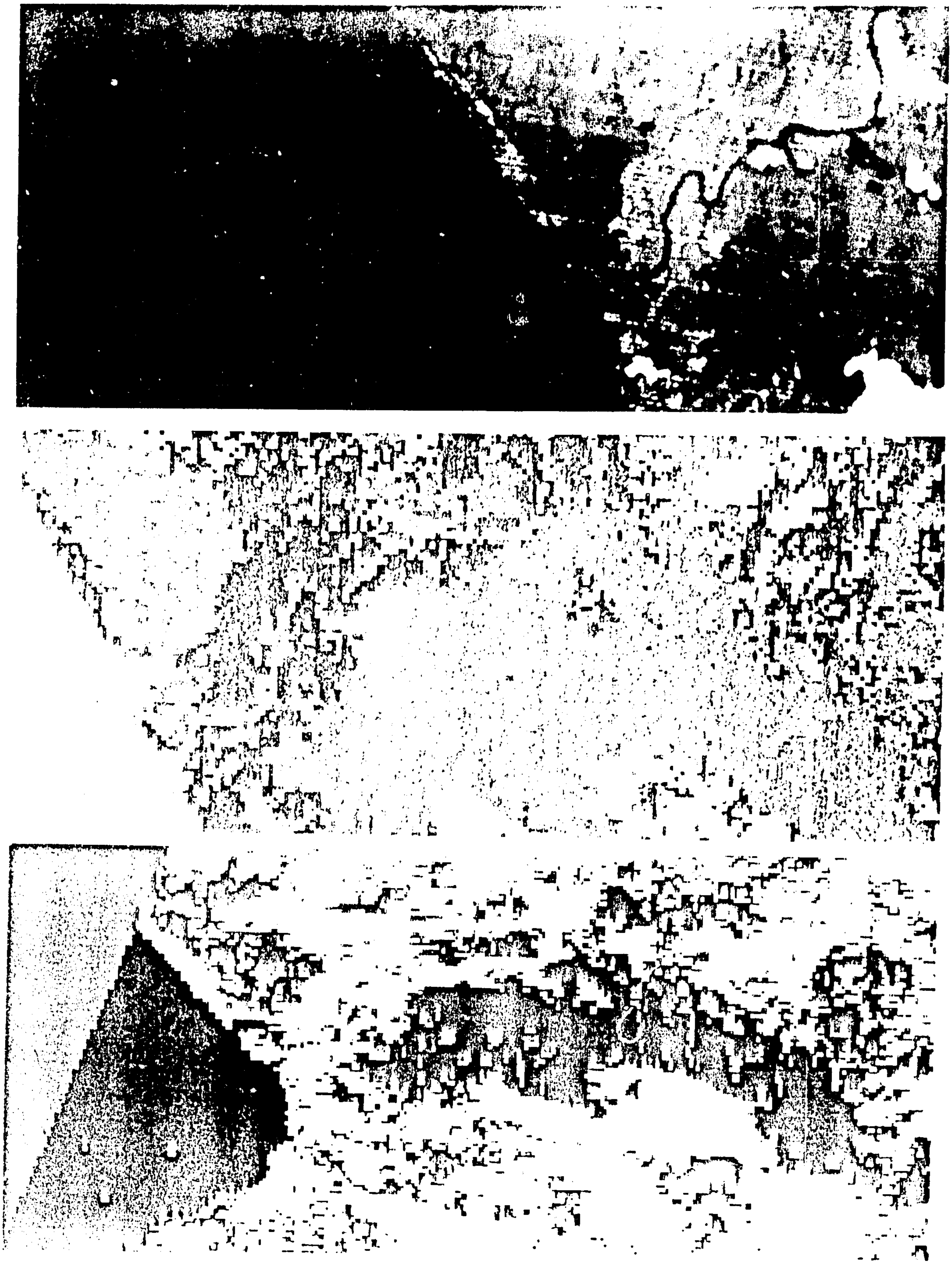


A

B

C

Photo 2-4: Comparison of aerial photography of the Tarcoles River and surrounding landscape. (Top, black and white. Middle, color. Bottom, color infrared.)



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At the conclusion of this project, a demonstration workshop was held in San Jose, Costa Rica to present and discuss these results. Similar presentations open to the general public were held at the Cultural Center in San Jose.

2.2.1.2 Conclusions

The following is a brief summary of the conclusions reached by Resources Development Associates concerning the Demonstration Project.

1. Aerial photography plays an extremely important role in resource surveys in Costa Rica. Color and color infrared (CIR) aerial photography have proven themselves to cost-effective data sources. Color infrared photography, at medium and low altitudes, is suitable for agricultural and urban delineations of the type required in Costa Rica. At medium altitudes over forest, color infrared was found to be superior, primarily due to the haze penetration capability of the film and filter combination. Color film was found to be slightly superior for low altitude (large scale) photography.

2. Medium scale photography is sufficient for Level III classification in Costa Rica (Appendices A-1 and A-2) but may need to be supplemented by large scale photography and ground truth verification. The map scale of 1:50,000 presently used in Costa Rica is complementary and compatible with these Level III applications. The medium scale photography is more efficiently transferred to the 1;50,000 map scale than is larger scale photography. For urban mapping applications where greater resolution and larger map scales are required, large scale color or CIR photography will be necessary.

3. Costa Rica does have the in-country capability to acquire (but not process) high quality color and color infrared photography at the scales desired.

4. Digital analysis of Landsat data can provide accurate Level I classification of approximately the same quality in Costa Rica as has been experienced in tests conducted in the United States and other areas. Visually interpreted Landsat imagery is generally inadequate for forest and urban cover delineations at the level of

detail required in Costa Rica (Appendix A-3). However, it does have value in other aspects of resource management; e.g., hydrological investigation, physiographic mapping, etc.

5. Minimum job costs for computer processing of Landsat may pose a problem for use in confined areas; e.g., urban studies in Costa Rica. Thus, if the urban sector must absorb total minimum job costs for computer processing, then digital Landsat data analysis will not be cost-effective for typical applications. On the other hand, if many of the potential users of this type of data can combine their efforts so as to make full use of a single processing of a Landsat frame then the cost-effectiveness of Landsat compares very favorably with other types of information acquisition for national planning.

2.2.1.3 Recommendations

The following is a brief summary of recommendations developed from the Demonstration Project.

1. Costa Rican governmental agencies responsible for management and planning in forest, urban, agriculture, and range programs, should consider systematically acquiring color and/or color infrared aerial photography where applicable, at a pace that can be efficiently handled by Costa Rican technicians. They should also provide for personnel training in equipment acquisition necessary for photointerpretation, film handling, and the development of a land resource data base. Film processing of the color and color infrared photography should be continued in the United States until such time as the national demand warrants development of in-country processing facilities. The Government of Costa Rica should utilize satellie imagery in a digital format for immediate assessment of land cover/land use and explore the possibilities of developing it as a continuing monitoring tool.

2. Costa Rican governmental agencies should encourage the development of a geographic based information system. Initially, the system can be composed of maps displaying a variety of resource themes. However, consideration should be given to adopting a computer-operated system in the future.

3. Costa Rican governmental agencies should continue and expand the training of analysts and other technicians via a series of workshops and training programs both in the United States and in Costa Rica. In this way, professionals in Costa Rica can also keep abreast of the rapidly developing field of remote sensing technology and its growing applications in natural resources inventory.

2.2.2 Pilot Project - Phase II

The challenge to Resources Development Associates and Costa Rican professionals was to design and demonstrate a system to meet the resource information needs of policy makers. Armed with an evaluation of the present resources condition, and supported by a regular flow of new information, planners will be able to recommend courses of action to ensure the forms of land use development that will be most beneficial to the country.

To attain this goal, a wide variety of data collection, processing, and and analysis techniques were employed. The resulting products were designed to be representative of those used in advanced resource surveys throughout the world. The intent throughout was that the methods used and the products derived would serve as a model which could be followed and employed in a nationwide survey (Phase III). To this end, technology transfer to Costa Rican professionals was an integral part of the project.

2.2.2.1 Goals

The major goals of the Pilot Project included the following items:

1. Completion of a land use inventory in the project area.
2. Development of an operational capability in Costa Rica to utilize the most appropriate remote sensing technology for resources survey, environmental survey,

monitoring or urban growth, and for regional management purposes.

3. To provide resources information of sufficient detail, accuracy, and reliability to support government management policy decisions in the aforementioned areas.

2.2.2.2 Description of Services

The project area agreed upon by the GOCR, USAID, and RDA extended from Puntarenas, on the Pacific Coast, to Limon, on the Carribean, completely encompassing San Jose and surrounding cities at its center (Figure 2-1). The survey concentrated on renewable natural resources and current land use.

Aerial photography was acquired by the GOCR in conjunction with RDA personnel for use in the project. Furthermore, ground information was collected and analyzed with the assistance of GOCR counterpart personnel. A land cover classification system was developed similar to the one proposed in the Demonstration Project.

The following items were completed in the course of the Pilot Project. Each task is referenced by a section number indicating where an explanation of the particular task can be located within this report.

1. A data collection system and analysis plan was designed using satellite data, aerial photography, ground data and other appropriate technology (Sections 4.0 and 5.0).

2. A film calibration program was carried out (Technical Annex 2).

3. Land cover maps were prepared from satellite data (Landsat) and aerial photography at scales of 1:200,000 and 1:50,000. To complement the land cover inventory, ancillary data (e.g., soils, geology, watershed, slope, etc.) were compiled as thematic maps at the aforementioned scales (Sections 4.2 and 4.5).

4. Aggregation and reporting of data by district for project-selected areas was completed (Appendix E).

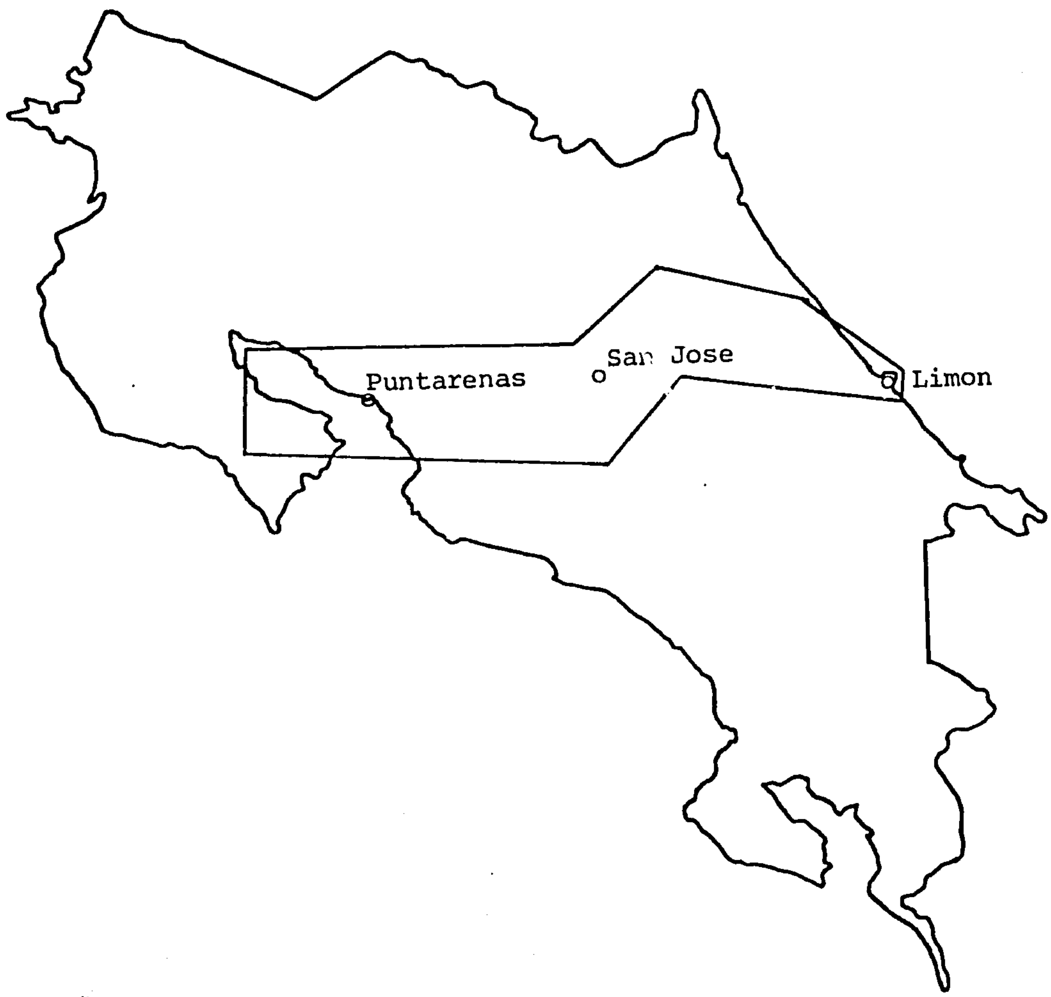

Figure 2-1: PILOT PROJECT PROPOSED STUDY AREA FOR NATURAL RESOURCES SURVEY

3.0 STRENGTHENING INSTITUTIONAL CAPABILITY IN NATURAL RESOURCES INVENTORY

A vital and primary goal of the project was the transferring of the technology employed to strengthen GOCR institutional capability in natural resources inventory and monitoring. The objective was to establish a continuing national capability to survey and monitor the natural resources of Costa Rica. This technology transfer (in the form of training) covered all phases of activity from data acquisition through map compilation and production to analysis and evaluation of the natural resources data.

A four-part training program was developed. The first part consisted of a two-week on-the-job training session for Costa Rican pilots and navigators who would be involved in future aerial photo mapping missions. This training coincided with the actual photo mapping missions which collected data for the Pilot Project. The second part of the training was an intensive four-week U. S. training course for Costa Rican professionals in the applications of remote sensing technology to natural resource inventory. Organized by RDA, this was conducted at the National Space Technology Laboratory in Mississippi and on the campus of San Jose State University in California. The third part of the course was on-the-job (OJT) training in Costa Rica during the ground truth/field checking parts of the inventory. The fourth part of the course consisted of OJT in California at the RDA facility. During this latter time, Costa Rican professionals applied the techniques and procedures developed to complete the resources inventory and assessment activity.

Several agencies within the Costa Rican Government have responsibility for different aspects of the national natural resources inventory. These include the Ministry of Agriculture and Livestock (MAG), the National Geographic Institute (IGN), the National Institute of Housing and Urbanization (INVU), the Planning Office of the Presidency (OFIPLAN), and the University of Costa Rica (UCR). A group of professional resource managers representing these agencies participated.

3.1 Aerial Photography Flight Planning and Film Handling

As emphasized throughout this report, aerial photography is an integral component of the natural resources information system in Costa Rica. Proper planning is essential to the success of an aerial photographic mission. A flight plan must be prepared in advance to ensure the success of the mission. Costs of the photo mission can be significantly increased if time is needlessly wasted while the plane, pilot and crew are in the air.

Film must be handled properly before, during, and after the photo mission. Improper film storage (espcially for CIR), incorrect camera settings, or improper processing could render the entire photo mission useless, if mistakes cause the aerial photography to fall short of acceptable project standards.

Mr. Robert Hardwick conducted a two-week OJT course in Costa Rica on photo mission planning, aircraft operations, photo mapping and aerial photography with color infrared films. President of Hardwick Aerial Surveys, Mr. Hardwick is an acknowledged expert on mapping and aerial survey operations, with more than 11,000 hours of flight experience in aircraft of all types. A major part of this experience has been gained on similar programs in Central and South America.

The training program was conducted using the IGN-based aircraft with the IGN photo crew and camera and the private pilots normally employed in operation of the aircraft. The program concentrated on operational experience and the use of simple aids, as opposed to classroom lecture. The aircraft was flown in full mapping configuration on five out of seven available days. It might be noted that, due to weather problems encountered later in the year, these "training" flights acquired more than 80% of all photography used during the entire course of the Pilot Project.

3.2 National Space Technology Laboratory Course

This training phase consisted of an introductory session conducted by the EROS Applications Assistance Facility located at the National Space Technology Laboratories (NSTL) in Bay St. Louis, Mississippi. The five Costa Rican students flew directly to this site from Costa Rica. Two RDA advisors accompanied the students through the one-week course.

NSTL was selected to present the introductory training session for several reasons. The Earth Resources Observation Systems (EROS) program of the United States Geological Survey maintains several training facilities in the United States. The NSTL facility specializes in training programs oriented toward the basics of remote sensing and traditional photo interpretation approaches. It was RDA's opinion that a comprehensive knowledge of the traditional photo interpretation methods should precede training in the more sophisticated technology of remote sensing, such as Landsat computer-assisted land cover classification. Also, resource surveys in Costa Rica will, to a large extent, entail manual interpretation of aerial photographs.

NSTL maintains a substantial amount of photo interpretation and related equipment. They also maintain a large library of aerial photography, Landsat imagery and remote sensing reference books. NSTL is located in a productive forest and agricultural region of the southern United States. Because of this, much of the photography and imagery used in the course are examples of forest and agricultural lands. The methods and techniques used for examples were highly applicable to conditions in Costa Rica.

One of the most important reasons for selection of NSTL over other facilities was the course's adaptability to the requirements of the Pilot Project. The course was designed to stress forest, land cover, and agricultural applications, and course enrollment was limited to members of the Costa Rican group. This allowed progression at a controlled speed with adequate time for individual instruction (Photos 3-1 and 3-2).

Photo 3-1: Classroom training at NSTL.

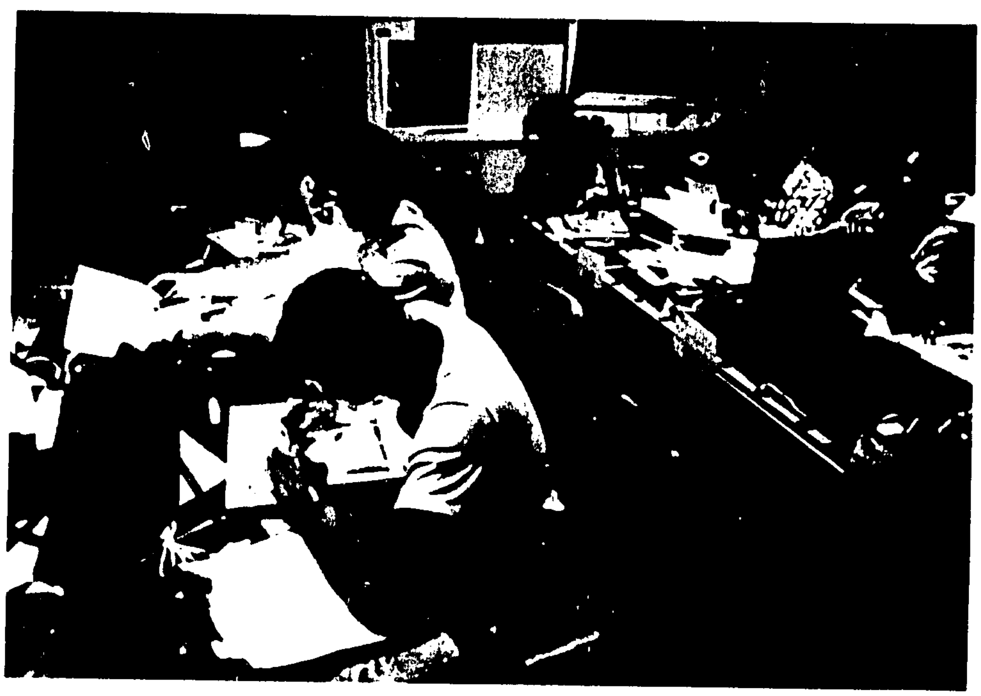

Photo 3-2: Laboratory exercises at NSTL.

The course itself was designed to provide an overview of the potential applications of remote sensing, an introduction to the theory, to manual and machine analyis of aerial photography, and a brief introduction to non-photographic imaging techniques. Course content is described in the NSTL outline presented in Appendix B-1. Besides lectures and laboratory exercises, ample opportunity was provided for each student to become acquainted with many types of interpretation/analysis hardware. This included rear-screen projectors, light tables, stereoscopes, color additive viewers, density slicers, image analyzers and digital planimeters.

No formal textbook was used during the NSTL course. Rather, a folder with a series of loose-leaf handouts and remote sensing examples was distributed.

At the conclusion of the program, the students were asked to provide a critique of both the contents and manner of presentation of the course. It appeared to be well-received by all. One comment was that the course was too short. Language presented only minor problems. Because the students' command of English varied appreciably, it was necessary to proceed slowly and clearly. One student with a fluent command of the English language often clarified matters to the others.

The next three weeks of training provided by RDA and SJSU expanded upon all of the areas presented in the NSTL introductory session.

3.3 Resources Development Associates/San Jose State University Course

At the conclusion of the NSTL course, the group flew to California to begin the RDA/SJSU segment of training. In order to take advantage of the facilities and expertise of the Geography Department of San Jose State University, arrangements had been made to conduct the training course as a joint effort with SJSU. In addition, SJSU provided three units of graduate college credit for each student completing the course. Seven instructors from SJSU and RDA participated in the training. They included Dr. Richard Ellefsen, Dr. David Schwarz, Dr. Duilio Peruzzi, Mr. Robert Campbell, Mr. Timothy Cannon, Mr. Kenneth Craib, and Mr. Steven Sader. As a matter of convenience, the students were housed in University dormitory facilities approximately two blocks from the classrooms.

The course itself was tailored specifically to emphasize the information needs of the Pilot Project. Course layout was designed by RDA. The specific content of each segment was the responsibility of the individual instructor. The course consisted of three basic components: lectures, laboratories and field trips. In general, each class day (running from 8:00 AM to 5:00 PM) was divided into one-half day of lecture (usually in the morning) and one-half day of either laboratory exercises or a field trip. The laboratories and field trips were designed to accentuate points made in the previous lecture. An outline of the course is found in Appendix B-2.

The first week of the course concentrated primarily on theory and remote sensing hardware. The hardware included photographic systems, non-imaging systems and sensor platforms. An introduction to multistage sampling, change detection and mission planning was also presented. The first week included field trips to the United States Geological Survey (USGS) facility in Menlo Park, California, the National Aeronautics and Space Administration (NASA) Ames Research Center in Mountain View, California, and the Conference of Latin American Geographers (CLAG) at Sonoma State University in Rohnert Park, California.

The USGS facility in Menlo Park is primarily responsible for preparation of topograhic maps from aerial photography. The students were given an extensive tour of the entire photogrammetric operation.

At NASA-Ames, they visited the NASA Airborne Instrumentation Research Project (AIRP). Since the beginning of the AIRP in 1971, more than 280,000 aerial photographs have been obtained, primarily over the eastern and western portions of the United States. The tour included a visit to the AIRP data facility where the computer-assisted geographic search system was demonstrated and an inspection of the U-2 high altitude aircraft system (Photos 3-3 and 3-4).

The students were invited to attend the Conference of Latin American Geographers at Sonoma State University. During the afternoon conference and an evening barbeque, the Costa Ricans were able to meet and exchange their views with many professional geographers from Latin America.

The second week of the course concentrated on potential applications of remote sensing data to various natural resource disciplines. Forestry, agriculture, and urban applications were emphasized. Data enhancement methods were also introduced. Two laboratories and three field trips were conducted. A field trip to the urban and agricultural sites around San Jose, California allowed the students opportunity to conduct ground truth exercises by identifying feature and object locations on a series of imagery and photographs of the area. Field trips were taken to two major manufacturers of digital image enhancement hardware: International Imaging Systems (I^2S), and Electromagnetic Systems Laboratory (ESL), Inc. At I^2S, the students observed a demonstration of the many enhancement possibilities of the I^2S System 101.

During the visit to ESL, the students first received a demonstration of the capabilities of the Interactive Digital Image Manipulation System (IDIMS). Then, an actual classification of a Landsat scene of Costa Rica was undertaken (Photo 3-5). The Pilot Project corridor had been previously outlined on Landsat scene E-2040-15163. This scene was digitally classified for land cover classes. Details of the digital classification procedure can be found in Section 4.2.1 of this report.

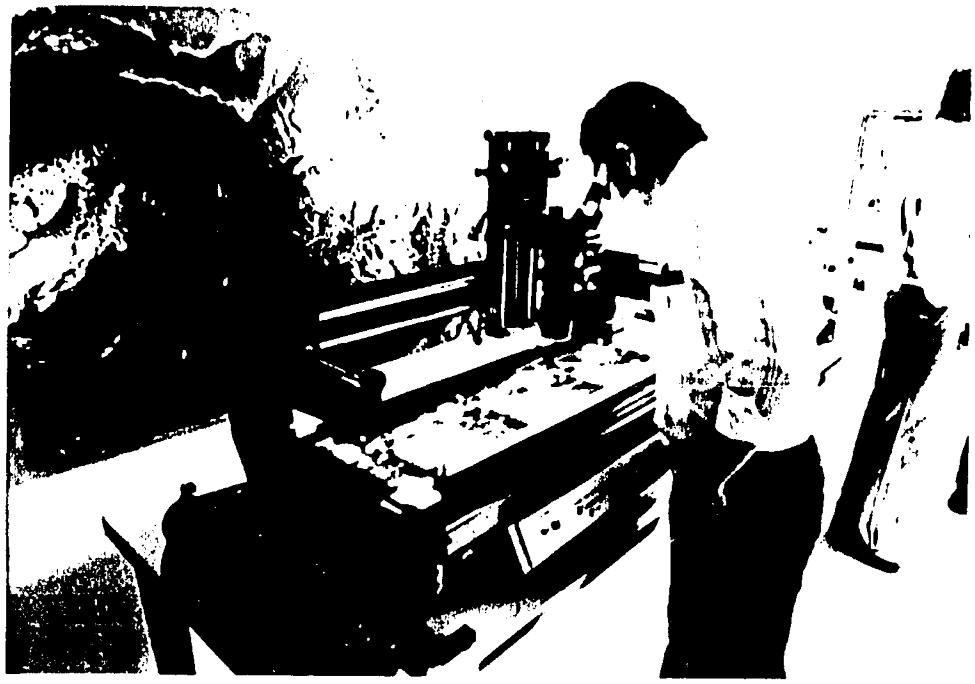

Photo 3-3: Photo interpretation equipment at NASA-Ames.

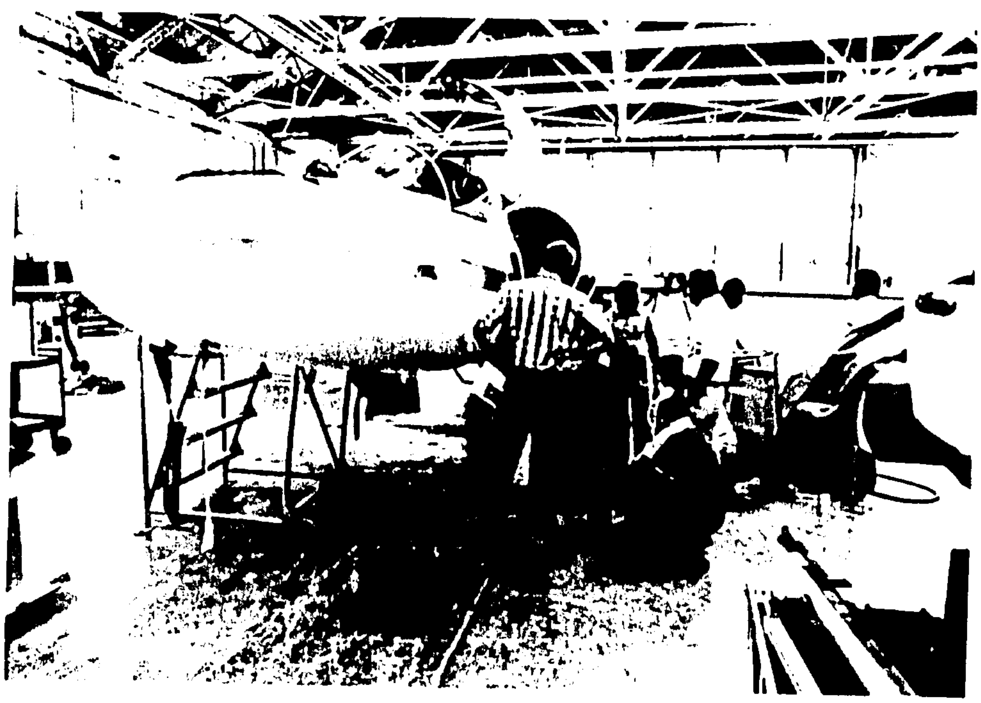

Photo 3-4: Costa Rican students inspecting U-2 reconnaissance aircraft.

Photo 3-5: Costa Rican students selecting "training areas" on IDIMS at ESL.

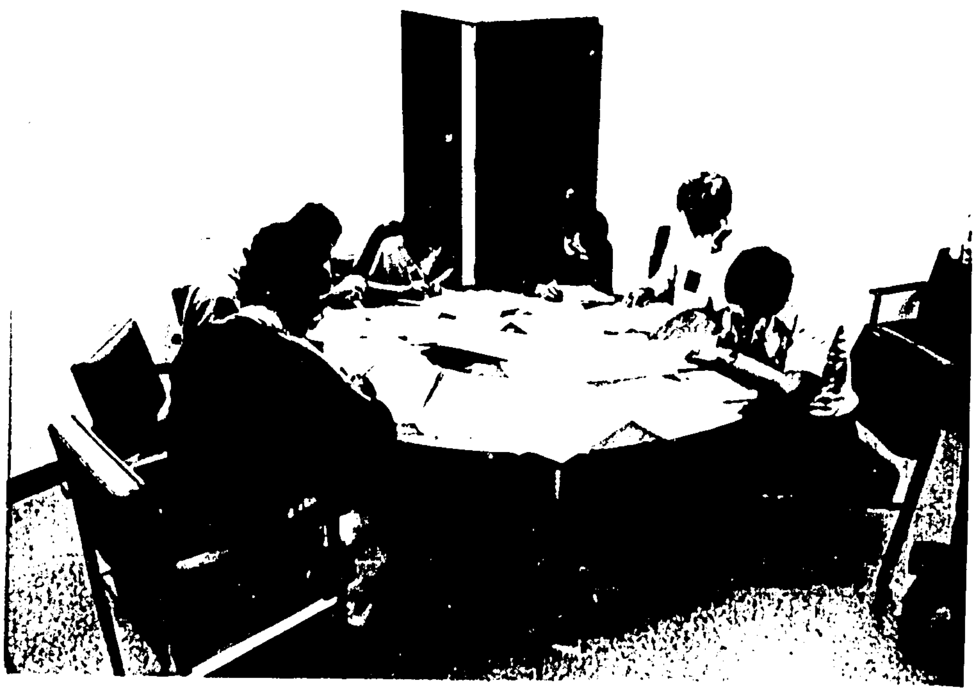

Photo 3-6: Costa Rican students selecting training sets: a step in the preparation for computer processing of Landsat data.

The Costa Ricans were responsible for selecting training areas and training sets for the Landsat classification (Photos 3-6). This classification was subsequently used in the Pilot Project. Although further work was necessary to create the final product, the original training sample selection done by the Costa Rican professionals proved to be excellent.

The third week of the course emphasized natural resource survey in Costa Rica using Costa Rican examples. Using the color infrared aerial photography obtained for the Pilot Project (Section 3.1), the students were instructed in techniques of land cover mapping, specifically forestry, agriculture and urban land cover. Cartographic techniques, geo-based information systems, land use planning techniques and the economics of remote sensing were stressed throughout the week. A second field trip to the USGS was taken. This time, the cartographic and map reproduction facilities were inspected. Toward the end of the week, considerable time was spent selecting ground truth sites on the photos and planning field work for the upcoming field training in Costa Rica. Again, the student knowledge of local conditions proved invaluable in this task. The last day of the course included a graduation ceremony during which each student was presented a certificate for satisfactory completion of the course.

3.4 Field Training in Costa Rica

RDA personnel and the Costa Ricans visited several ground sites throughout the project area to discuss natural resource problems and the task of mapping land cover/land use types in Costa Rica. The 1:40,000 CIR aerial photos were used to compare the land cover types at various ground locations with their appearance on the photos. USAID and IGN vehicles and drivers were provided for daily outings to destinations near San Jose (e.g., Grecia sugar cane and Naranjo coffee producing areas; Irazu agricultural area) and for two- or three-day excursions to more remote destinations (e.g., Guapiles-Siquirres-Limon, banana, cocoa, and forest producing area; Puntarenas-Orotina-Jaco, agriculture, cattle and forest producing areas).

With extensive field coverage of the many land cover/land use types encountered within the project area and constant reference to the aerial photography throughout the field travel, the project participants gained the knowledge and confidence necessary to extrapolate their identification and mapping of land cover types to areas that could not be visited due to limited access. Section 4.2.3 provides a detailed description of the photographic land cover mapping.

3.5 U. S. On-the-Job Training Program

The last segment of the training was a two-week on-the-job training program held at the RDA facilities in Mountain View, California. The purpose of this segment was to allow the students to assist with preparation of various output products required for the completion of the Pilot Project. The session was deliberately scheduled late in the year so that this would be possible. It was expected that all of the land cover mapping, assigned to the Costa Ricans during the ground truth training session, would be completed by this date and could be transferred to the appropriate map base.

Numerous tasks were included in this last training program. They included:

1. finalization of Landsat land cover classification,
2. completion of land cover mapping from the color infrared aerial photographs,
3. transfer of the land cover data to the base maps using the zoom transfer scope, vertical sketchmaster, and map-o-graph,
4. edge-matching of map sheets,
5. area measurements using digital planimeter,

6. detailed mapping of soil types,

7. preparation of Landsat black and white mosaics,

8. land cover mapping from visual interpretation of Landsat,

9. aggregation of Landsat data for final map transfer,

10. comparison of final Landsat classification with land cover class from visual interpretation,

11. inspection of slope, drainage, and watershed mapping techniques.

In addition, informal lectures and work sessions were conducted on the subjects of physiographic mapping and multistage sampling. The session was concluded in a day-long conference where future plans were discussed. The Costa Ricans were given the opportunity to critique the training program and Pilot Project. In addition, they offered viewpoints concerning priority areas for a continuing natural resources program and recommended various strategies to carry out this work successfully.

4.0 NATURAL RESOURCES INVENTORY

Lack of detailed and up-to-date information concerning the status of current land use and renewable natural resources has hampered the development of sound land use planning and resource management policies. These policies cannot evolve without a reliable information base to support decision making. Given the existing constraints of time, budget, and trained manpower, introduction of a new technology may be the only feasible method to provide an urgently needed natural resources inventory.

Traditional ground mapping methods are prohibitively time-consuming and expensive for a nationwide inventory of natural resources. Recently developed techniques of remote sensing can provide an effective alternative.

Remote sensing from aircraft and satellites has gained worldwide recognition as a efficient method to provide earth resources information that is often not feasible techically or economically to obtain by conventional ground methods. Remote sensing is neither a panacea for all resource information needs nor is it capable of totally replacing ground data collection methods. Remote sensing techniques are a potentially valuable tool when used in properly designed natural resource programs.

A current land use and natural resources inventory was conducted for the Pilot Project. The inventory was not limited to data collection by satellite and aircraft sensors, but also included existing and newly generated ancillary and terrain data (soils, watershed, slope) to allow more comprehensive evaluation of locational land resource attributes.

The inventory procedures discussed in this section include some of the most advanced equipment and techniques available. However, much care was taken to prepare an information base which would be responsive to the GOCR's needs while being compatible with their capabilities to operate and maintain it.

With this in mind, all land cover data obtained from remote sensors and ancillary data were compiled at common (national topographic) map scales prior to their preparation and presentation in thematic map form.

The inventory data displayed as individual and composite land resource "themes" provided the medium for further analyses and evaluation. Particular resource themes were used to synthesize a new map (land management) which displays biophysical zones that have intrinsic suitability to support particular land uses. This map illustrates the steps required to develop a land classification system in Costa Rica that yields location-specific information concerning land use capability and suitability for resource development.

The following sections (4.1 through 4.6) present the components of the natural resources inventory as a chronological sequence of events, beginning with data collection from remote sensors and progressing through to the presentation of all resource data in map form.

4.1 Data Collection from Remote Sensors

The remote sensing data used in the Pilot Project incorporate multistage, multiplatform, and multitemporal concepts. Multistage refers to the varying altitudes (and resultant photo scales and ground coverage) from which remotely sensed data were obtained. The stages included satellite and various scales of color, color infrared and black and white aerial photographs.

The concept of multiplatforms is a related one and identifies the type of craft and particular cameras or other sensors employed. The platforms that provided data for the Pilot Project were the Landsat Satellite and the IGN-leased Cessna aircraft.

Multitemporal refers to the collection and/or comparison of data from at least two different dates. Multitemporal data were used in determining land use changes occurring over a specified period of time.

A discussion of the Landsat data and aerial photography acquired for the Pilot Project follows.

4.1.1 Satellite (Landsat) Data

The popularity of Landsat* may be attributed to its ability to collect data over virtually all of the earth's surface on a regular and repetitive basis. With two satellites in sun-synchronous orbit, any area on the earth's surface can theoretically be imaged every nine days.

Cloud cover remains a serious problem for any remote sensing effort in Costa Rica. During the rainy season, approximately June through November, clouds cover most of the country. Even during the dry season, most of the higher mountain peaks are often shrouded in clouds. Between January 1974 and July 1978, a total of 16 Landsat images were collected over the San Jose area. Cloud cover in these images ranged from 20% to 51%. In the same period, 14 images had been collected over Limon with cloud cover ranging from 20% to 90%, giving an average of 63% (Appendix C-1). Most of these images were collected during the dry season. Of the total of 30 images available for these two areas, only 10 were acquired during the June-November wet season. Appendix C-2 provides a graphical representation of annual cloud cover as sensed by Landsat. Appendix C-3 presents a list of the 30 available Landsat scenes together with their "scene ID" numbers for ordering purposes.

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* For the readers who are not already familiar with Landsat, the characteristics of the satellite, located in Technical Annex 1, will provide an introduction to this section.

Another problem in the acquisition of Landsat data for Costa Rica is the necessary reliance on the "on-board" satellite tape recording system, as nearly all of Central America is out of range of the present ground receiving stations. The use of tape recorders carried on-board the satellites is generally limited in an attempt to save them for only the highest priority data gathering needs. The tape recorder was "turned on" over Costa Rica only after a special request from the Office of the President of the United States to NASA.

All Landsat images are now referenced to a worldwide grid system of row and column coordinates. Since nominal scene centers remain constant, this allows easy and reliable retrieval of appropriate scenes for a particular location. Figure 4-1 shows the row/path coordinates for scenes covering Costa Rica. As can be seen, most of the country can be covered by two images, the "San Jose" image at Path 16, Row 53, and the "Limon" image at Path 15, Row 53.

Black and white prints and color composites were obtained for the best of the 1975 and 1977 Landsat images, specifically the 3 March 1975 San Jose image (Photo 4-1), the 12 February 1975 Limon image, and the 1 August 1977 San Jose image. A computer compatible tape (CCT) (#E-2040-15163) provided data for the computer-assisted land cover classification (Section 4.2.1). Photo 4-1 shows a copy of this scene.

Black and white prints (bands 5 and 7) were also obtained for the 9 April 1978 Limon image. Unfortunately, due to problems at NASA/Goddard, no CCTs were available for any 1978 Landsat scene over Costa Rica and RDA was unable to obtain a CCT for any Limon scene of any date with acceptable cloud cover. Therefore, a visual interpretation of the 1978 Limon scene was performed as a substitute for the computer-assisted classification originally desired (Section 4.2.2).

Landsat data are available through the USGS EROS Data Center at Sioux Falls, South Dakota. A copy of the EROS order form can be found in Appendix C-4. Average "turn-around" time for receipt of most Landsat products has been 30 to 45 days with prepaid orders.

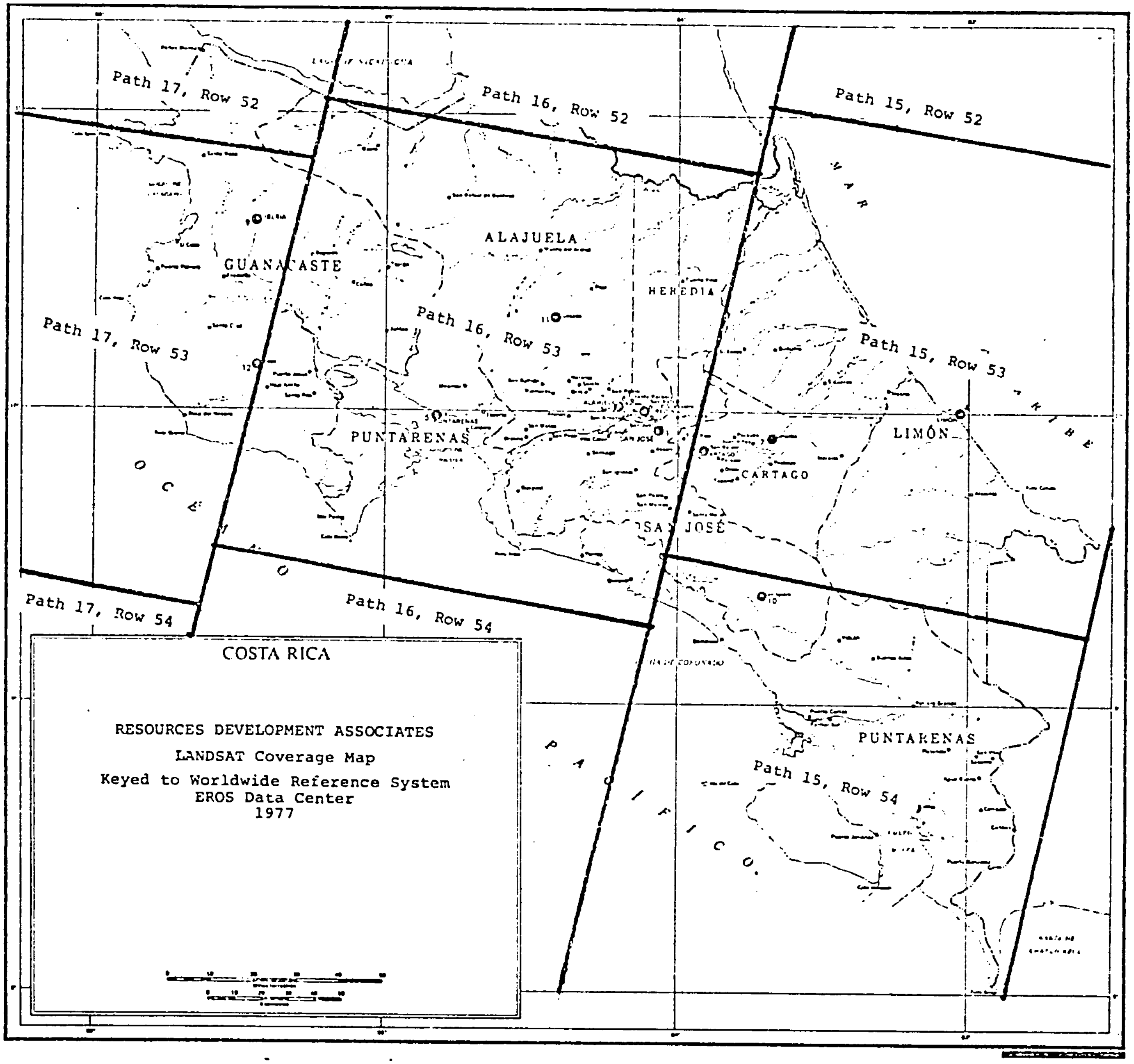


Figure 4-1: LANDSAT COVERAGE MAP OF COSTA RICA

4.1.2 Aerial Photographic Data

The Instituto Geografico Nacional (IGN), under the Ministerio de Obras Publicas (MOP), is charged with the responsibility for aerial photography acquisition (and map preparation). The IGN maintains a series of aerial cameras and has its own team of aerial photographers and photo technicians. IGN does not, however, own or operate photo mapping aircraft. For mapping missions, the IGN leases the services of a local privately-owned twin-engine Cessna 401. The aircraft has been modified to accept a Zeiss RMK 14/23 mapping camera (9 by 9 inch film format) equipped with an Automatic Exposure six inch focal length lens cone. With a typical fuel load and a standard crew, this aircraft can reach a maximum altitude of 28,000 to 30,000 feet (approximately 8,500 to 9,100 meters) above mean sea level.

The IGN maintains a complete capability to process and print panchromatic and black and white infrared film. Prior to the beginning of this program, however, they had little experience with color or color infrared aerial films. The complicated chemistry of these films dictates careful handling before, during, and after exposure (particularly the case with color infrared film) and processing is similarly complex (see Technical Annex 2). The photographic data collection program for the Pilot Project was structured with these constraints in mind.

Great reliance was placed on aerial photography for land cover and land use information. Color infrared photography taken especially for the project, was the principal data used. Supported by natural color photography and traditional black and white photography, both current and historical, interpreters were able to identify a wide variety of land cover/land use classes.

The original program plan called for color infrared photography to be collected over the majority of the study area at a scale of 1:50,000, followd by color aerial photography at a scale of 1:25,000 over selected areas. An instructor pilot with substantial experience in photographic mapping operations and the use of color infrared (CIR) film was provided through RDA to assist in the initial aerial photo flights to provide training in both photo aircraft operations and CIR film handling (Section 3.1).

Plans were originally made to begin the aerial photography program on or about 3 January, to coincide as nearly as possible with the onset of the "dry season" and good flying weather. Unfortunately, several delays were encountered in obtaining necessary contract signatures and clearances in Washington, and the first aerial photographs were not obtained until 25 January 1978. This delay in project initiation had an unexpectedly severe impact on the overall program. The normally good photo flying season was cut short by an unusually high percentage of cloud cover, which seriously curtailed high altitude flying for aerial photography. This situation continued throughout the year with relatively few of the cloud "breaks" normally encountered in Costa Rica.

A second problem involved the survey aircraft leased by the IGN. When flown for aerial photographic mapping purposes, an aircraft's heading, attitude, altitude, speed and ground track must all be held within carefully defined limits. This requires precision flying and a responsive aircraft. As flying height is increased, and the air becomes less dense, it is correspondingly more difficult consistently to hold the aircraft within these limits. Although the aircraft leased by the IGN demonstrated that it could reach an MSL (mean sea level) altitude of 28,000 feet, in the opinion of the instructor pilot it could not maintain this altitude and still operate within the limits imposed by a production photo mapping mission. The aircraft operated comfortably within limits at an MSL altitude of 25,000 feet.

Terrain altitude in the Pilot Project area varies from sea level to more than 6,000 feet above sea level. Since constant photo scale is strongly desired in any regional resources survey and mapping operation, a decision was made to reduce the flying height requirement and accept photography at a uniform scale of 1:40,000. Given the available Zeiss camera, this photo scale would be consistent with a height of 20,000 feet above terrain, or flight altitudes of from 20,000 to 26,000 feet MSL over the project area.

CIR aerial photography was obtained at this scale over approximately three-quarters of the project area (Figure 4-2). The remaining area could not be photographed due to excessive cloud cover. It should be noted that 80% of this photography was acquired during the first week of the project. Although the photography obtained did not cover the entire study area, it was felt that it did cover the areas of primary concern, and a decision was made to proceed with the project as planned. The 1:40,000 CIR images met the analysts' requirements for sufficiently fine ground resolution to permit identification of the types of land cover/land use required for the land cover mapping program (Section 4.2.3). More information could be obtained from the positive transparencies than from prints, especially through the use of the modern optical viewing devices employed in the project.

4.2 Land Cover/Land Use Classification

The choice of an appropriate classification system is a prerequisite to any land cover/land use inventory. The classification system utilized in the Pilot Project was adapted from a U. S. Geological Survey (USGS) classification that is in common usage with land cover mapping programs in the United States (13). The USGS classification was developed primarily for remote sensing in temperate climates; therefore, it was necessary to make some revisions for applications in tropical Costa Rica. Key requirements of the system included:

1. development of classes which properly represented all the forms of land cover/land use found in Costa Rica;

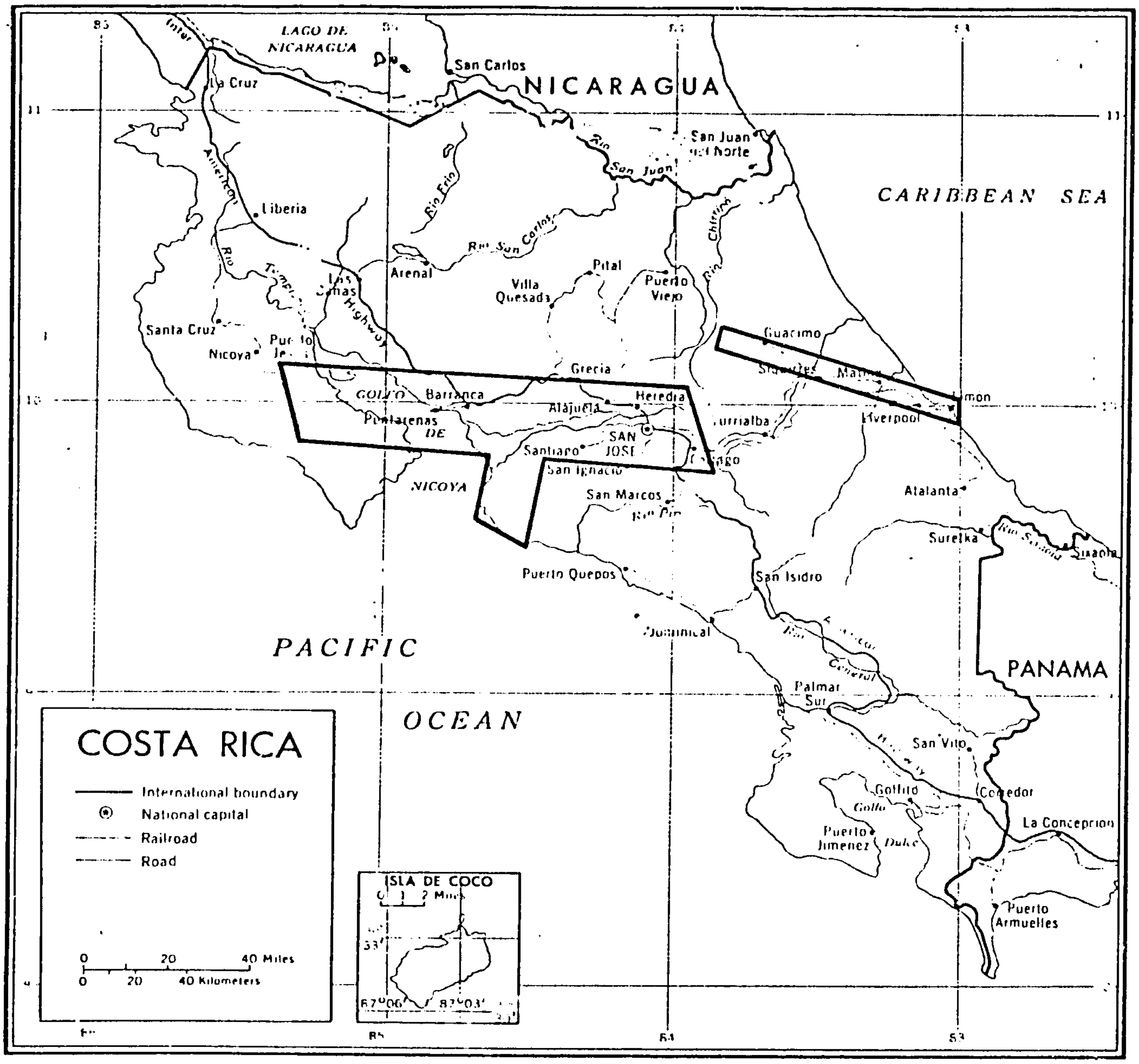


Figure 4-2: COLOR INFRARED AERIAL PHOTOGRAPHIC COVERAGE FOR THE PILOT PROJECT (JANUARY 1978; 1:40,000 SCALE)

2. that features identified were those which planners needed in evaluating the nation's resource base;

3. that the classes selected would endure over a long period of time so that a continuing monitoring system could be established;

4. that all the classes could be accurately identified on the type and scale of photography which had been obtained; and

5. that the classes would be as compatible as possible with those which could be derived from the computer processing of the Landsat digital data.

All of these requirements were successfully met in the final version of the system. Further, the system has scope for compatible additions in the future if more intensive resource mapping needs arise. Obvious additions would be statements of quality related to specific condition forest or of residential areas.

The principal feature of the USGS classification system is the identification of discrete land cover types as logical subdivisions of broader categories. For example, Level I is comprised of broad classes such as "agriculture" or "urban" areas, while Level II allows for separation of seasonal and perennial crops, and Level III may be used to indicate discrete crops or land uses. Level I classes were broad enough to embrace all land cover classes in Costa Rica, but Level II and III designations were required in most cases.

In using this classification system, the interpreter will in most cases actually identify "land cover", or existing vegetation, and from this will infer "land use". As an example, Class 31 - Grass Dominant - is a land cover class that may be associated with grazing by cattle or other ruminants. Unless the interpreter can actually see cattle in the photograph or has access to other ancillary data, however, he cannot be absolutely sure the land is currently used for grazing. For these reasons, the term "land cover/land use" is employed throughout this report.

The full classification system employed in Costa Rica is presented in Table 4-1. Classification by this system provides land cover/land use information suitable for broad resource planning and management programs.

4.2.1 Landsat Computer-Assisted Classification

While the synoptic view obtained from the Landsat visual image provides useful general data on land cover, it is the digital form of Landsat data which offers the level of detail required for a resource inventorying and monitoring system of the quality required in this project. Accordingly, digital data in computer compatible tape (CCT) format were acquired and processed by computer to produce land cover/land use maps. The principal data set employed covered a large proportion of the Pilot Project's study area. Unfortunately, because of technical difficulties within NASA, CCT data from recent satellite passes were unavailable and analysts were obliged to use data from the dry season of 1975. Although the data were not current, clear demonstration was made of the efficacy of the data and the requisite computer processing to inventory land resources. Processing was accomplished using one of the more modern systems available, the Interactive Digital Imagery Management System (IDIMS) developed and maintained by Electromagnetic Systems Laboratory (ESL) of Mountain View, California. The full interactive feature of the system was employed by RDA analysts and the Costa Rican professionals.

The ESL IDIMS is a combination hardware-software system for general purpose, interactive, multi-user image processing, including multispectral analysis and classification. The hardware includes a Hewlett-Packard 3000 Series II Computer, an interactive processing console with a programmable array processor, and three channels of memory with video color display. The IDIMS has the capability to perform a number of operations relating to radiometric, geometric and cosmetic corrections of

Level I	Level II	Level III
1—Urban	11—Residential	111—Residential (low building density)
		112—Residential (medium building density)
		113—Residential (high building density)
	12—Commercial and Services	
	13—Industrial	
	14—Transportation, Communications, & Utilities	
	15—Industrial and Commercial Complexes	
	16—Public & Private Institutions	
	17—Non-built upon Surfaces	171—Recreation
		172—Vacant Urban land in transition
2—Agriculture	21—Seasonal Agricultural	211—Grains
		212—Vegetables
	22—Perennial	221—Coffee
		222—Bananas
		223—Sugar Cane
		224—Palms (oil & coconut)
		225—Cocoa
		226—Other
	23—Greenhouses and other agricultural structures and settlements	
	24—Agricultural land in transition	
3—Grass and Brush Cover	31—Grass dominant; >70% grass	
	32—Grass with significant brush component or tree component; >40%	
	34—Brush dominant; >60% brush	
	35—Brush with significant tree components; >60% brush; >20% trees	
4—Forest	41—Broadleaf (evergreen & deciduous)	411—High, high density
		412—High, medium density
		413—High, low density
		414—Medium, high density
		415—Medium, medium density
		416—Medium, low density
		417—Low, high density
		418—Low, medium density
		419—Low, low density
	42—Mangrove	
	44—Forest plantations	
	45—Palms (natural)	
	46—Forest land in transition (recently cleared)	
5—Water	50—Ocean, marine estuaries	
	51—Streams, canals	
	52—Lakes	
	53—Reservoirs	
	54—Aquaculture	
6—Wetland	61—Marsh	
7—Barren Land	71—Beaches, docks	
	72—Bare, exposed rock	
	73—Stripmines, quarries	
0—No Data		

Table 4-1: LAND COVER/LAND USE CLASSIFICATION

the image data in addition to data enhancement techniques. Furthermore, the system can be trained to cluster and classify data into groups which represent different types of land cover.

The Landsat MS (Multispectral Scanner System)S collects four sets of spectral data which represent the relative spectral reflectance values of earth surface features in four distinct wavelength regions. Different land cover types reflect light in different intensities and wavelengths, while members of the same land cover type tend to reflect light in a similar manner. If one were to inspect the reflectance values for many different plots of "forest", he would find them to be similar, although seldom identical. If he were to compare these values with those representing "grass", he would find a noticeable and consistent difference. If the statistical (mean, standard deviation) characteristics of a class are sufficiently different from those of another class, then the two may be effectively separated.

A sample of an unknown class may be compared to each of the defined and statistically unique classes and may then be assigned to that class to which it is most similar. Figure 4-3 shows the spectral reflectance value distribution associated with four hypothetical land cover classes. Their means are represented by various symbols. The "contour" lines represent the distribution of members of the classes. Since each class is represented by four sets of reflectance values (or digital numbers for each band, DN), a graphical representation of its distribution ideally requires four-dimensional space. This figure shows some of the two-channel combinations which are possible. With the use of all four channels of data, all four of the classes can be uniquely and accurately identified and separated. However, using only two channels, for instance MSS4 and MSS5, there is an overlap of spectral characteristics of several classes. These distributions of spectral characteristics may be termed "decision spaces". Classification of an image then involves partitioning the four-dimensional decision space into zones defined by the positions of the classes specified as significant by the analyst.

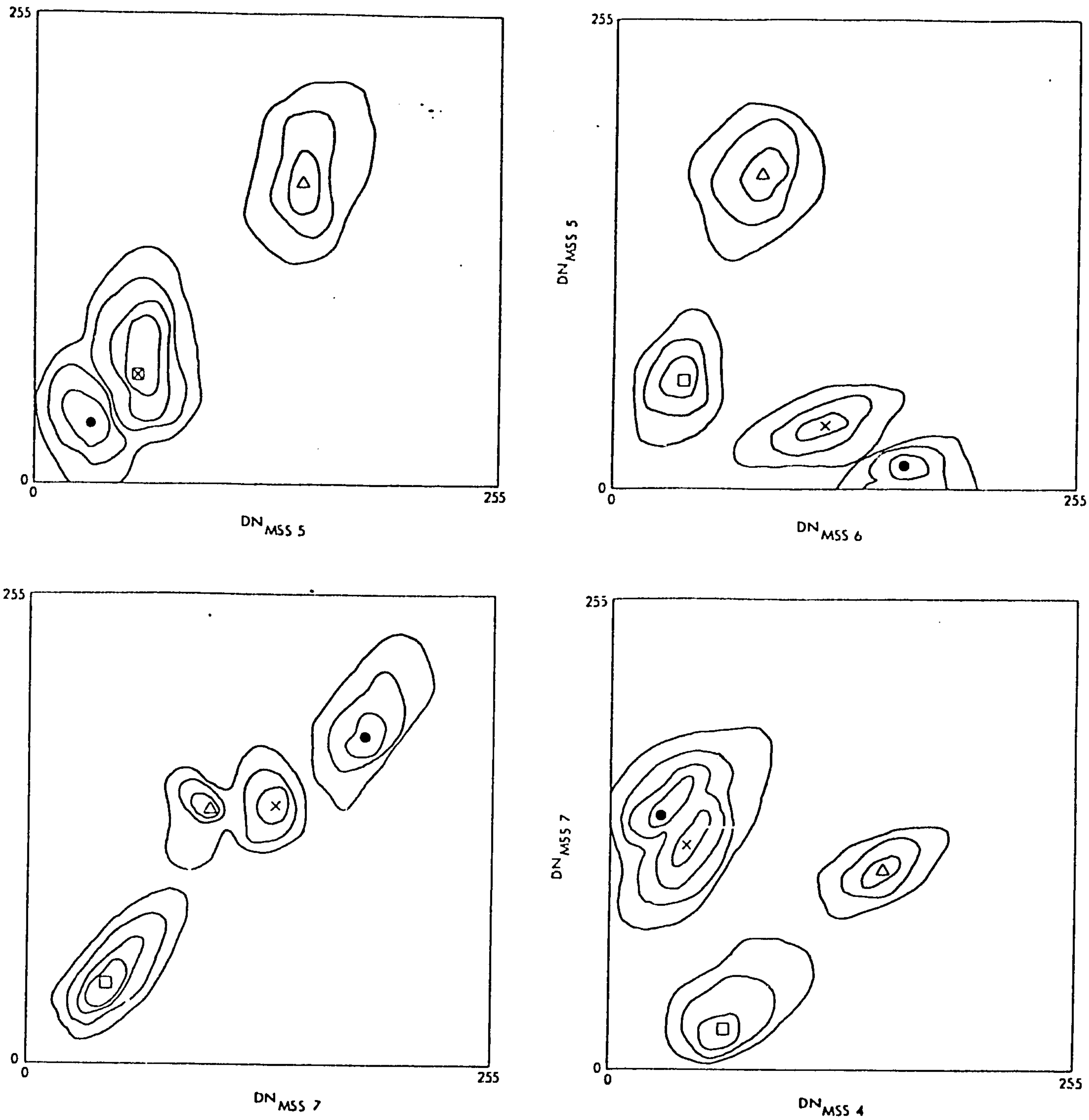


Figure 4-3: FOUR-CLASS REFLECTIVE VALUE DISTRIBUTION

Each "pixel" (minimum Landsat resolution element) from the image will lie within one zone or another and thus can be considered similar to the pixels used to define that class.

There are two basic approaches to obtaining data from which decision boundaries can be established. These are referred to as supervised and unsupervised approaches. In the supervised approach, the analyst specifies areas which, in his opinion, typify the land cover classes of interest. These are referred to as "training areas". Statistics computed by analyzing these training areas are then used to establish clusters defining a land cover class. In the unsupervised approach, the analyst allows the computer to define classes by inspection and spearation of the four-dimension decision space into clusters based on distribution of the total data. The analyst must then attempt to correlate the image classes with the "real world" to construct land cover classes. The classes selected should adequately delimit and define items of interest and must not only be separable from all others but should be significant to the analyst.

For the Pilot Project, a combination supervised/unsupervised approach was chosen to select the training areas. The classification algorithm employed was the "maximum likelihood" classifier. Final output was geometrically corrected and scaled to 1:50,000 and 1:200,000 IGN topographic maps. The following procedures were required to reach this end:

1. radiometric rectification and cosmetic correction,
2. training set selection and clustering, class statistics determination,
3. maximum likelihood classification,
4. photographic verification,
5. stratification and cover class grouping,
6. geometric correction,
7. scaling and output products,

8. tabular statistics.

Each of these steps is described in the order that they occurred.

4.2.1.1 Radiometric Rectification and Cosmetic Correction

The multispectral scanner aboard the Landsat satellite "scans" the earth below six contiguous lines at a time, by employing six individual sensors per spectral band. Due to the differences between the radiometric transfer functions of these sensors, the resulting images often exhibited an objectionable striping effect that can be remarkably difficult to remove. Although this striping is often categorized as a cosmetic defect, these banding artifacts interfere with classification accuracy and tend to mask subtle tonal gradations such as sediment plumes in bodies of water. The IDIMS possesses several smoothing functions which were used to deal with this problem. Bad data lines or points in a Landsat CCT were flagged with a pixel bit value of 255. Since only seven bits are used by Landsat, this 255 value could not be a "valid" pixel value. On this basis, the Landsat function in IDIMS removed the bad line or point by replacing it with the previous line or point. This was an automatic procedure which occurred during tape input to all other processing.

4.2.1.2 Training Set Selection and Clustering

As soon as the original satellite data were entered into the computer, the training set selection process began. Training set selection was performed by the Costa Rican students during their first visit to the United States (Section 3.3). The Landsat image was displayed in color composite format on the color video monitor. A combination of supervised and unsupervised approaches was used.

Where the analyst had specific knowledge of areas in the scene, the supervised method of selecting training sets was used. This generated a small number of specific classes. For the remaining portion of the study, large areas representative of the ground cover types were selected and used with unsupervised clustering. Beginning with the supervised approach, the analyst then located known land cover types on the Landsat scene, outlined them and generated a statistical record. Using a trackball which locates an image point on the video screen, the analyst outlined an irregular polygon around the ground feature and then entered the reflectance data within the polygon to the STAT function. In the original supervised training, 20 specific land cover types were developed. Using the trackball, examples of each of these 20 classes were collected by the Costa Ricans (Photo 3-5). These 20 classes were identified as:

Water 1	Forest 2	Central City
Water 2	Grass	Commercial
Clouds	Mangrove	Commercial Industrial
Shadow	Mixed Pasture	Residential Commercial
Fresh Water	Cane	Mixed
Bare Rock	Mixed Agriculture	Coffee
Forest 1	Pasture Extensive	

Following completion of the supervised training set selection, the analyst allowed the computer to enter the unsupervised mode. Using an algorithm called RANDSAMP, the computer randomly selected small rectangles throughout the scene, sampling a specified percentage of the entire scene. In this case, the sample was 15% of the total area of the scene. This sample, temporarily treated as one class, was combined with the classes defined under the supervised approach and submitted to several statistical algorithms.

The STAT function generated one statistical record for each set of input data. The information in the statistical record consisted of:

1. the mean value of the grey level data from each band,
2. a covariance matrix, which is a measure of the size and shape of the cluster of points used to generate the statistics.

The data from STAT were input to a function called ISOCLS. The result of using ISOCLS was that the reflectance data of the original training set, including the large heterogeneous RANDSAMP class, were inspected for homogeneity. If, indeed, one had selected a training area which contained more than one class, the computer would separate it into the appropriate subclasses. In the case of the Costa Rican data, many of the training classes were subdivided repeatedly. This was not surprising since some of the original classes were recognized as non-homogeneous; e.g., "mixed agriculture", "mixed pasture", etc. Table 4-2 shows the number of classes which resulted from the segregation of each original single class. A total of 86 separate classes were created by ISOCLS.

There was a very good chance that several of these 86 classes represented the same cover type; in fact, they may have had virtually identical statistics. A cross-correlation was performed on these 86 classes. Results indicated that this was indeed the case. Curves representing the spectral signature of each of the 86 classes were prepared by the Costa Rican students (Photo 3-6). Figure 4-4 is an illustration of these curves. The curves were constructed by plotting the means, bracketed by one standard deviation, of the four bands of spectral data for each cover class. Inspection of shape and amplitude of these curves allowed a determination of similarity between classes. Using the results of the cross-correlation, it was possible to identify class pairs having a great similarity. By comparing the spectral curves for these classes, it was possible to confirm that they

Name of Original Class	Number of Separated Classes
Water 1	1
Water 2	1
Clouds	3
Shadow	1
Fresh Water	1
Bare Rock	1
Forest 1	3
Forest 2	4
Grass	2
Mangrove	2
Mixed Pasture	2
Cane	6
Mixed Agriculture	8
Pasture Extensive	6
Central City	4
Commercial	1
Commercial Industrial	1
Residential Commercial	3
Mixed	9
Coffee	4
Randsamp	23
TOTAL	86

Table 4-2: ISOCLS SEPARATION OF LANDSAT SPECTRAL CLASSES

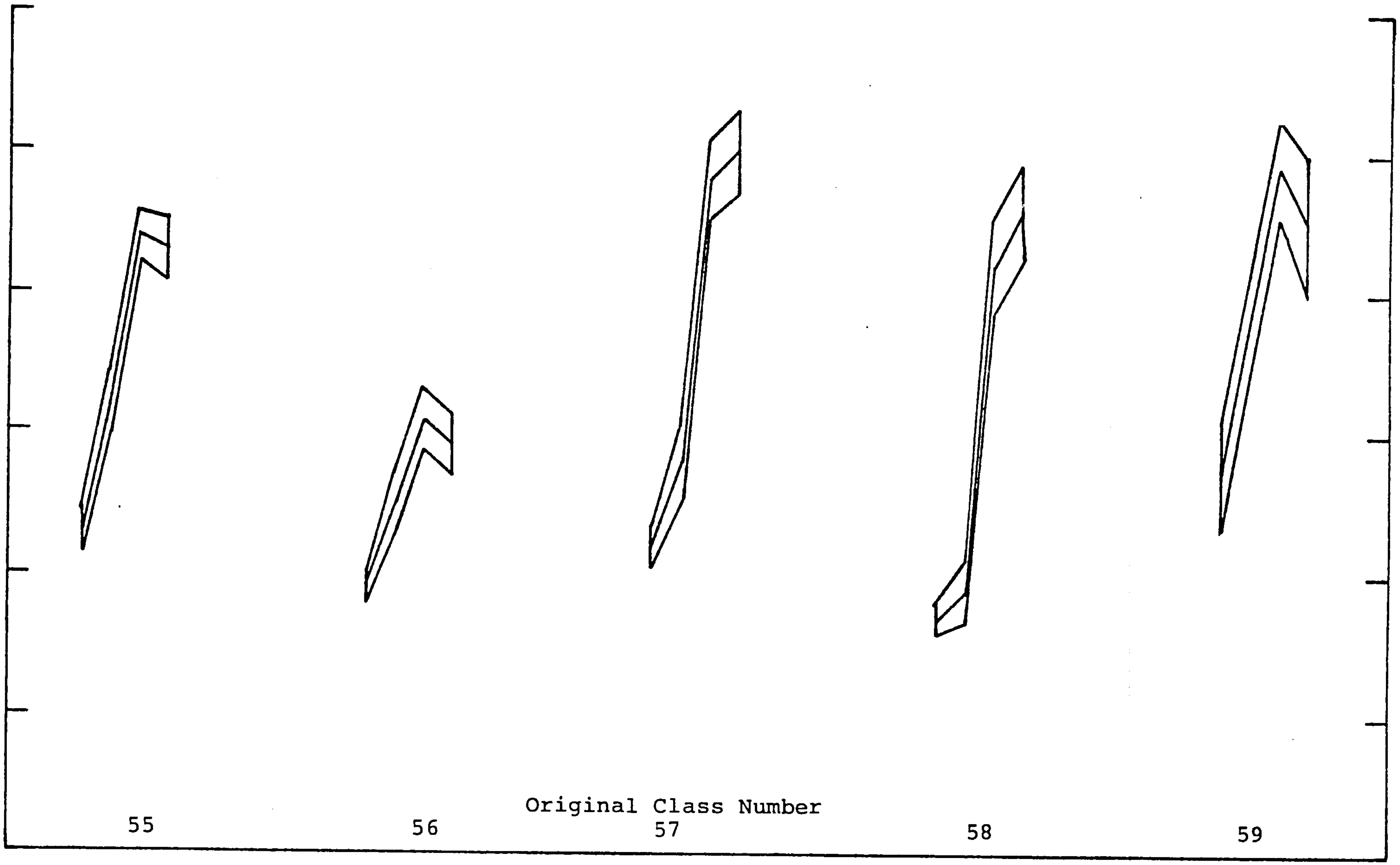


Figure 4-4: AN EXAMPLE OF LANDSAT SPECTRAL CURVES

were indeed the same cover class. At that point, either they could be combined into one class or one of the two could be discarded. By making many such determinations, the 86 classes were reduced to 42.

The final set of statistics for these 42 classes was then used as input to the maximum likelihood classification for the entire project area.

4.2.1.3 Maximum Likelihood Classification

Classification, as defined here, refers to the process of asisgning each of the pixels of a Landsat scene or subscene to a land cover class based on the set of input statistics generated by the user training set selection.

The maximum likelihood classification considered all the information present in the statistical record. In comparing each Landsat pixel element against each of the cluster statistics, the mean value was used together with the covariance matrix which defined the "shape" of the cluster (decision boundary). The algorithm used consisted of evaluating a probability density function for each pixel element and assigning the pixel to the cluster (class) for which the probability was a maximum.

The classification algorithm used a maximum likelihood discriminant rule under the assmption of multivariate Gaussian distributions. The joint Gaussian probability functions for each class were estimated in the training process. The mean vectors and covariance matrices were computed for each sample.

To classify a pixel X, the following likelihood function was computed for each class i:

$$g_i(X) = -\frac{BANDS}{2}\log(2\pi) - \frac{1}{2}\log|C_i| - \frac{1}{2}(X-\mu_i)^T C_i^{-1}(X-\mu_i)$$

where:

C_i = covariance matrix for class i
$|C_i|$ = determinant of covariance matrix for class i
μ_i = mean vector for class i

The pixel X belonged to class i if: $g_i(x) \geq g_j(X)$ or all $j \neq i$.

Inevitably, there were points in the area classified which obviously did not belong to any of the classes defined by the training samples. The classification procedure necessarily assigned these points to one of the training classes, but typically they were expected to yield very small probability values.

The output from the maximum likelihood classifier was a line-printer map of the entire area at a scale of 1:24,000, representing full Landsat resolution. Each pixel (approximately 1.1 acre or about 0.45 hectares) was represented by one character. All 42 classes were represented. Figure 4-5 is an example of the classification for an area on the eastern side of the Nicoya Peninsula. Classes 1, 2, 5, and 6 represent water classes. A line has been drawn around them to help identify the coastline.

At this point in the analysis procedures, most of these classes have not yet been assigned to any specific land cover class. This is the goal of the photographic verification process which follows.

4.2.1.4 Photographic Verification

The objective of this step in the analysis procedure is to correlate the computer generated classes with actual land cover classes through comparison with color infrared aerial photographs of the area.

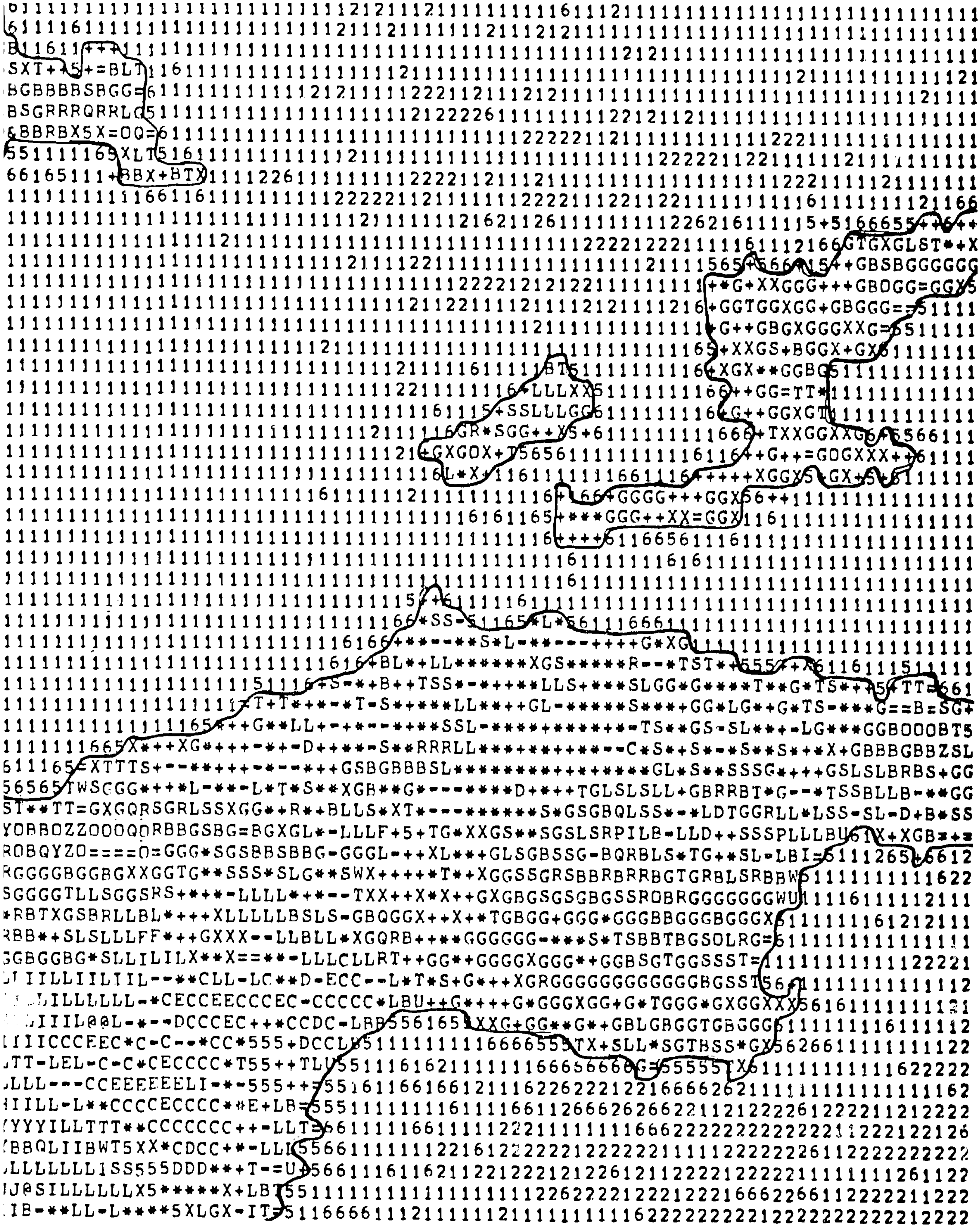


Figure 4-5 : MAXIMUM LIKELIHOOD CLASSIFICATION 42 CLASSES

The most difficult portion of this task was locating identifiable features on the computer printout. When mosaiced together, the printout covered an area of approximately five meters by four meters. The only easily recognizable features were clouds and certain geographic features; e.g., stream intersections, shorelines, or forest boundaries. These features were used as points for comparison of the computer printout symbols with the land cover type that could be identified on aerial photos.

Spectral curves were drawn for all of the 42 classes (Appendix C-5). Many of these classes were incorporated or grouped based on similarities of their spectral signatures. Each group of spectral classes was then assigned to one of the final 14 land cover classes which they represented (Table 4-3). These classes included most of the Level I and some Level II classes. In many cases, this assignment was straightforward. However, in some instances, a spectral class representing a particular land cover class in one geographic area might represent a different land cover class in another geographic area. Table 4-4 lists the most common "confusion classes". In most cases, this "confusion" could be logically explained. For instance, the spectral class for coffee confuses with both forest and brush. Indeed, coffee bushes reflect light similar to brush. Furthermore, one variety of coffee is commonly shaded by trees, sometime spectrally similar to a less dense forest. Urban areas are made up largely of concrete, asphalt, and shadow which may appear spectrally similar to rock, sand, or bare soil.

This problem was minimized through a geographic stratification which reduced misclassification by assigning one spectral class to one land cover class in each stratum.

Forest

Mangrove

Coffee

Grass 1 - Lush-growing, Green Grass

Grass 2 - Dominantly Dry Grass

Grass 3 - Dry Grass with Brush Component

Brush

Cane

Cut Cane

Bare Soil/Wet Soil

Urban 1 - Central City

Urban 2 - Commercial/Residential, Medium Density

Urban 3 - Commercial/Residential, Low Density

Other - Water, Clouds, Shadow

Table 4-3: FINAL 14 LAND COVER/LAND USE CLASSES DERIVED FROM COMPUTER PROCESSING OF LANDSAT DATA

Forest	Mangrove
Shadow	Stream Course
Bare Soil	Urban
Dry Grass	Cut Cane
Coffee	Forest
Coffee	Brush
Bare Soil	Water
Grass	Cane
Urban	Dry Grass
Urban	Cut Cane

Table 4-4: LAND COVER CLASSES COMMONLY "CONFUSED" OR REPRESENTED BY THE SAME CLASSIFICATION SYMBOL ON THE LANDSAT COMPUTER PRINTOUT

4.2.1.5 Stratification and Land Cover Class Grouping

In an attempt to eliminate a source of systematic misclassification discussed in the previous section, the Landsat image was divided into seven geographic strata. Each spectral class was assigned to one land cover class in each stratum. All strata were recombined to form a revised composite classified image. Each stratum was kept as large as practically possible. The confusion classes were much too common to allow individual stratification of each minute area.

The major part of the image was treated as a single unit (Stratum 7) and was considered a baseline from which the other strata deviated. The remaining six strata encompassed only about 20% of the entire image. In order to differentiate between urban areas and bare soil, an urban stratum was constructed. Within the urban stratum, those spectral classes representing the urban and bare soil classes would be labelled "urban" (Table 4-5). Outside the urban stratum, those spectral classes were labelled "bare soil". In the same manner, a cane-mangrove stratum was delineated. Within the stratum, the grass 1 and 2 spectral classes were labelled "cane", the grass 3 class was labelled "cut cane", and the forest classes were labelled "mangrove". Outside of the stratum, these classes retained their original names: grass 1, grass 2, grass 3, and forest. The same reasoning held for creation of sugar cane and coffee strata.

In some instances only a part of the spectral classes that represent a land cover class are confused with other land cover classes. For example, of the original 42 classes, eight represented forest. Of these eight, only five confused with mangrove within the mangrove stratum. The remaining three always represented forest. Likewise, six forest classes became coffee in the coffee stratum and two remained forest (primarily dense forest classes).

Cluster Class Number	Stratum 1 San Jose Urban	Stratum 2 Urban General	Stratum 3 Puntarenas Urban	Stratum 4 Pacific Cane/Mangrove	Stratum 5 Grecia Sugarcane	Stratum 6 San Jose Coffee	Stratum 7 Western Grass-Brush Forest
1	Water	Water	Water	Water	Water	Water	Water
2	Water	Water	Water	Water	Water	Water	Water
3	Clouds	Clouds	Water	Water	Clouds	Clouds	Clouds
4	Clouds	Clouds	Water	Water	Clouds	Clouds	Clouds
5	Shadow	Shadow	Water	Water	Shadow	Shadow	Shadow
6	Water	Water	Water	Water	Water	Water	Water
7	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil
8	Coffee	Forest	Forest	Forest	Forest	Coffee	Forest
9	Coffee	Forest	Forest	Forest	Forest	Coffee	Forest
+	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil	Bare Soil
*	Coffee	Brush	Brush	Brush	Brush	Coffee	Brush
&	Grass 3	Grass 3	Grass 3	Cut Cane	Cut Cane	Grass 3	Grass 3
@	Coffee	Forest	Forest	Forest	Forest	Coffee	Forest
=	Urban 2	Urban 2	Urban 2	Water	Bare Soil	Urban 2	Water
A	Coffee	Forest	Mangrove	Mangrove	Forest	Coffee	Forest
B	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3
C	Forest	Forest	Mangrove	Mangrove	Forest	Forest	Forest
D	Forest	Forest	Mangrove	Mangrove	Forest	Forest	Forest
E	Coffee	Forest	Mangrove	Mangrove	Forest	Coffee	Forest
F	Coffee	Forest	Mangrove	Mangrove	Forest	Coffee	Forest
G	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3
H	Grass 1	Grass 1	Cane	Cane	Cane	Grass 1	Grass 1
I	Grass 2	Grass 2	Cane	Cane	Cane	Grass 2	Grass 2
J	Grass 1	Grass 1	Cane	Cane	Cane	Grass 1	Grass 1
K	Grass 1	Grass 1	Cane	Cane	Cane	Grass 1	Grass 1
L	Coffee	Grass 2	Cane	Cane	Cane	Coffee	Grass 2
M	Grass 3	Grass 3	Cut Cane	Cut Cane	Cut Cane	Grass 3	Grass 3
N	Grass 3	Grass 3	Cut Cane	Cut Cane	Cut Cane	Grass 3	Grass 3
O	Urban 3	Urban 3	Grass 3	Cut Cane	Cut Cane	Grass 3	Grass 3
P	Grass 3	Grass 3	Cut Cane	Cut Cane	Cut Cane	Grass 3	Grass 3
Q	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3
R	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3
S	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3	Grass 3
T	Urban 2	Urban 2	Urban 2	Bare Soil	Bare Soil	Bare Soil	Bare Soil
U	Urban 1	Urban 1	Bare Soil	Bare Soil	Urban 1	Urban 1	Bare Soil
V	Urban 2	Urban 2	Urban 2	Bare Soil	Urban 2	Urban 2	Bare Soil
W	Urban 2	Urban 2	Urban 2	Bare Soil	Bare Soil	Bare Soil	Bare Soil
X	Urban 2	Urban 2	Urban 2	Bare Soil	Bare Soil	Bare Soil	Bare Soil
Y	Urban 3	Urban 3	Urban 3	Cut Cane	Cut Cane	Grass 3	Grass 3
Z	Urban 3	Urban 3	Urban 3	Cut Cane	Cut Cane	Grass 3	Grass 3
/	Water	Water	Clouds	Cut Cane	Cut Cane	Water	Clouds

Table 4-5: COVER CLASS GROUPING FOR GEOGRAPHIC STRATA

The actual construction of the strata required some prior knowledge of the areal distribution of the cover types. For instance, it was known that major fields of cane occurred north of Puntarenas. Inspection of the Landsat image allowed the cane areas to be outlined. The same type of procedure was followed for the other strata.

Strata boundaries were outlined on a 1:250,000 Landsat color composite. The boundaries were identified by their geographic coordinates and entered into the ESL computer. The digital information was used to divide the image into the seven individual strata. Photo 4-2 shows a colored representation of the seven strata. White areas represent Stratum 1 (San Jose Urban) and Stratum 2 (Urban-General). The light yellow is Stratum 3 (Puntarenas-Urban). Yellow is Stratum 4 (Pacific Cane/Mangrove), orange is Stratum 5 (Grecia Sugar Cane), green is Stratum 6 (San Jose-Coffee), and blue is the baseline stratum: Stratum 7 (Western Grass/Brush/Forest). Photo 4-3 shows the strata boundaries overlayed on a grey-scale representation of the classified image. Photo 4-4 show an enlargement of Stratum 4 with its cover class assignments as different colors.

The cover class assignments to each stratum are listed in Table 4-5. The "Cluster Class Number" is the symbol which represents that particular spectral class on the original 42-class printouts. After assignment of these class names to each of the 42 classes in each of the seven strata, the image was recombined to form the final classified image.

The classified image was inspected at this point by displaying it on the color video monitor and assigning a particular color to each class. Photographs wee taken of the television screen during this process. Photo 4-5 illustrates the classification for the entire project area. Photos 4-6 and 4-7 show enlargements of the Puntarenas and Tarcoles areas respectively. The color assignments in each of these three photos are:

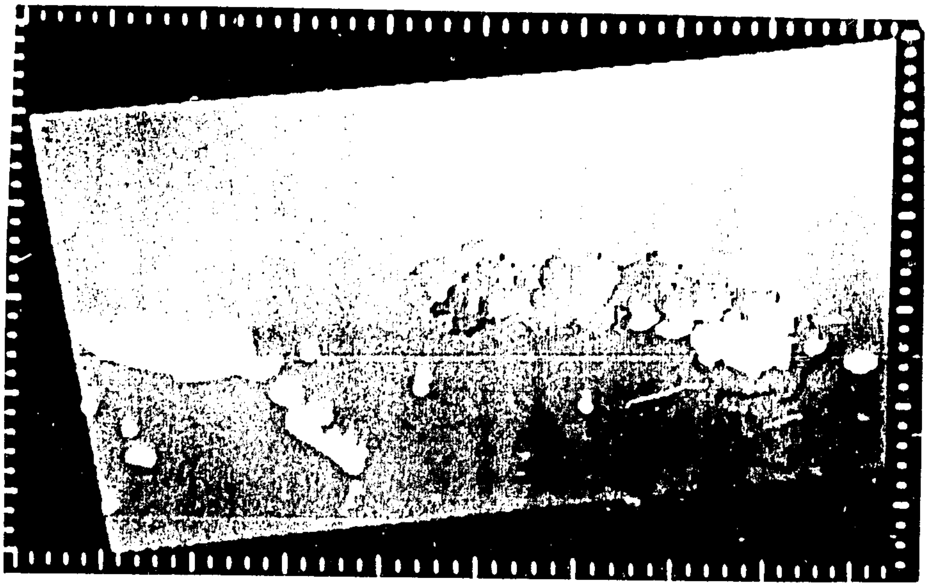


Photo 4-2: Geograp strata locations.

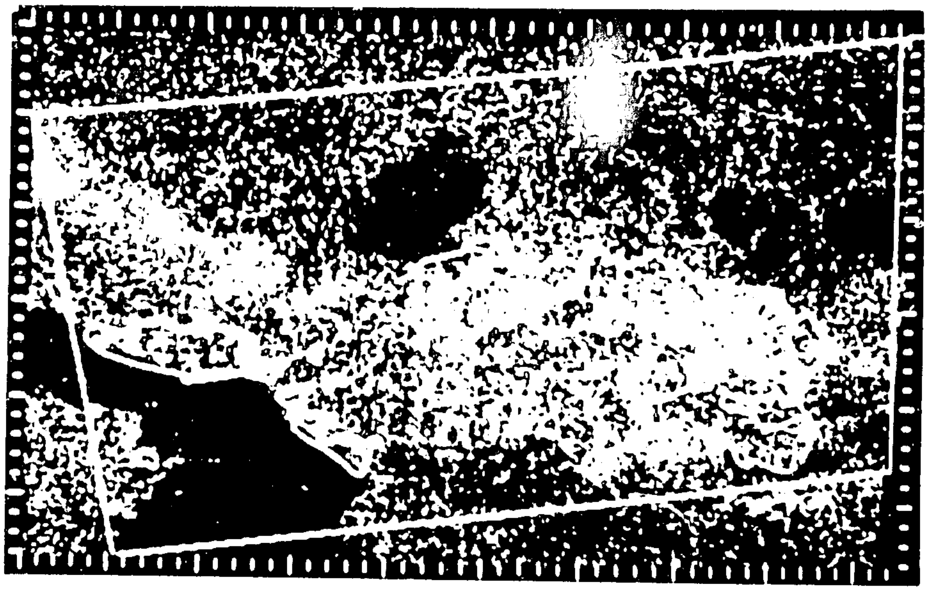


Photo 4-3: Geograp strata boundaries o grey-scale image.

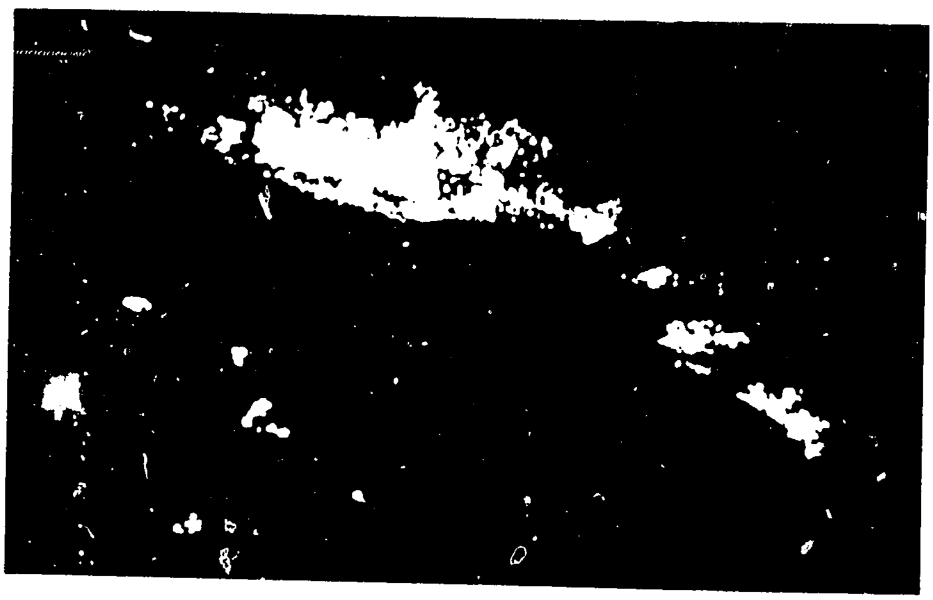


Photo 4-4: Stratum 4 (Pacific Cane/ Mangrove)

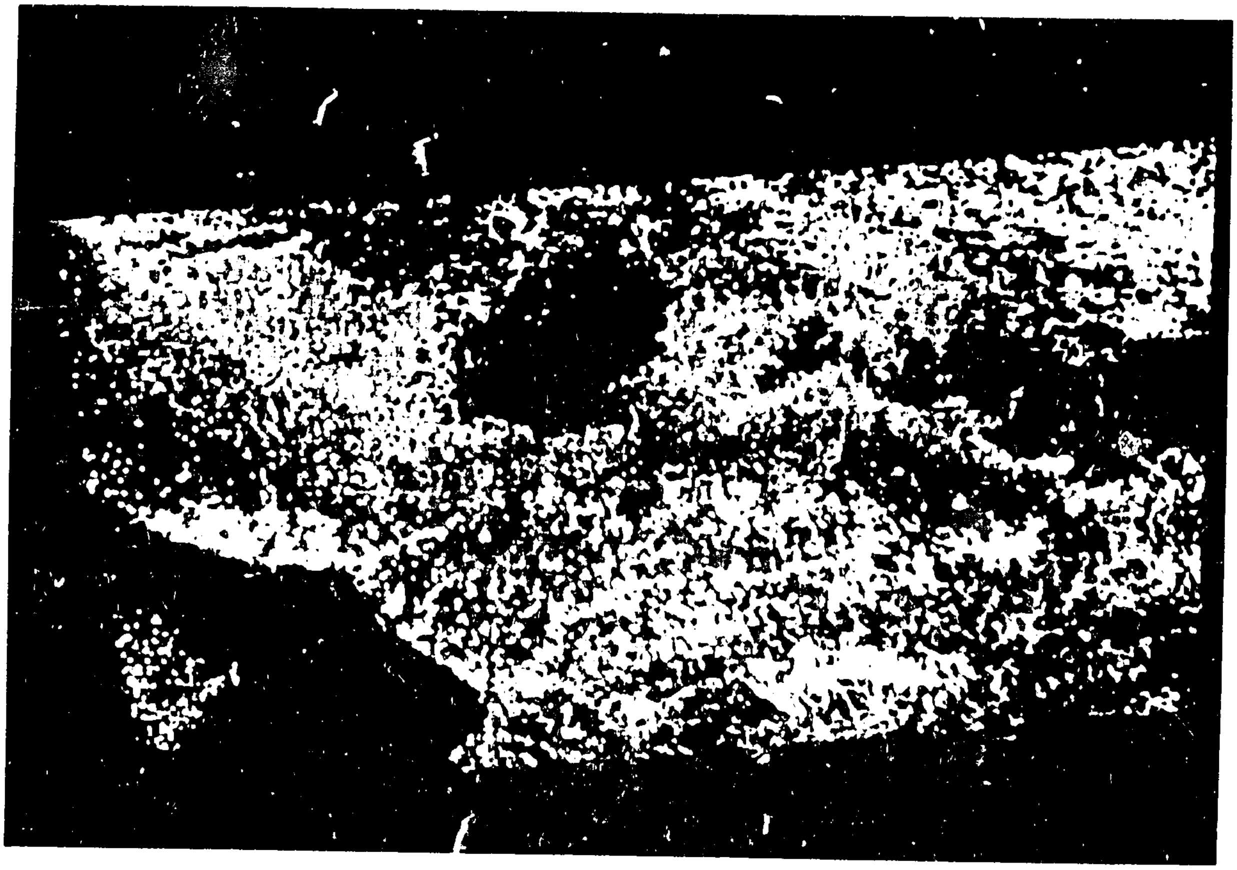


Photo 4-5: Stratified classification of Pilot Project area.

[illegible] Puntarenas area.

Photo 4-7: Stratified classification of Tarcoles area.

Forest - Light Green	Cane - Dark Blue
Mangrove - Pink	Bare Soil - White
Coffee - Dark Green	Urban - Light Blue
Grass - Brown	Water, Clouds, Shadow - Black
Brush - Red	

4.2.1.6 Geometric Correction

One of the major advantages of Landsat imagery is its repeatability and consistency. This characteristic can be exploited for several purposes, among them map-making, generation of mosaics, temporal analysis between several images, or detailed area measurement. However, the imagery as received in its "bulk" form possesses numerous inaccuracies in its geometric display of the ground surface. One cannot directly match the imagery to a geographic map base. Particular inaccuracies are inherent in the Landsat system.

Earth rotation during the scan causes a "skewing" of the image. In uncorrected scenes, this effect is most conspicuous in rectilinear ground features such as city streets or agricultural fields which display a skewed character with non-perpendicular corners.

Scanning mirror nonlinearities result in non-uniform spacing between the ground points corresponding to successive samples in a given line. This distortion affects only the horizontal (samples) direction.

Platform attitude fluctuations including changes in satellite velocity and altitude from the nominal values cause very complex distortions.

Detector commutation effects result in subtle band-to-band misregistration and a slight "sawtooth" type of distortion most evident on linear features.

Line length "corrections", consisting of replicated pixels at certain sample intervals, are deliberately introduced into the data by NASA in order to expand the sensor data records of a given scene into a "standard" line length. This normalization is required because the satellite's scanning mirror is subject to long-term drifts in period. This adjustment causes difficulties if the two images being registered contain replicated pixels at different sample intervals. The original line length before line length adjustment was performed is provided on the Landsat CCT and the pixels which were inserted may be removed.

Although there are numerous other factors (such as the shape of the earth's geoid) which must also be accounted for, they are all implicitly included in the correction method used in this study.

On the IDIMS system, geometric correction can be performed by a function called REGISTER, which automatically deskews, rotates, squares pixels and matches the image to control points selected interactively by the operator. The simplified form of this correction involves using four control points and results in a scale error of no more than 1% to 2% in the corrected image. By using multiple ground control points, greater accuracy can be achieved and the more complex distortions can be eliminated from the data.

The input image can be resampled in the coordinate system of the output image using nearest neighbor replication, bilinear interpolation or higher order approximations to the ideal sin(x)/x resampling function (such as the cubic spline). While images resampled via "nearest neighbor" rules suffer the least loss of sharpness, linear features such as roads and bridges present a sawtooth effect at the cost of significantly greater computation time, hence expense. Approximations to the sin(x)/x convolution offer slightly better performance, but consume even more computer time. For this study, the nearest neighbor option was used.

Fifteen geometric correction control points were picked. These were points which could be accurately identified on both the Landsat image and an IGN 1:200,000 base map. The latitude and longitude of each point, accurate to 0.1 minute of arc were determined from the map. Appendix C-6 provides a list of these points. Their location on the Landsat image is identified by blue dots (much larger than the actual points) on Photo 4-8. They were chosen to spatially represent the project area and to form a rather equidimensional net within it. The locations of the points on the image were entered into the computer or "digitized". A transformation was then applied to the image data and the data was resampled according to the nearest neighbor assignment. The nearest neighbor assignment is explained in Section 4.2.1.7. The output of this task was a classified image in a geometrically-corrected format.

4.2.1.7 Resampling and Generation of Output Products

If each pixel of a Landsat scene is represented by a single alpha-numeric character on a standard line-printer, the resultant scale of the output will be approximately 1:24,000. To produce a map which has a scale that is an even increment of this scale (1:12,000, 1:48,000, etc.), one could either sample every other line and column (every third line and column, etc.) or duplicate each pixel. However, to produce a scale which is not an even increment requires resampling of the data (e.g., 1:50,000 and 1:200,000).

The three most common resampling techniques in order of accuracy, difficulty, and thus expense, are the nearest neighbor assignment, bilinear interpolation, and cubic convolution. The first of these, the nearest neighbor assignment, produces a very acceptable resampling, and in the interests of economy was chosen for use.

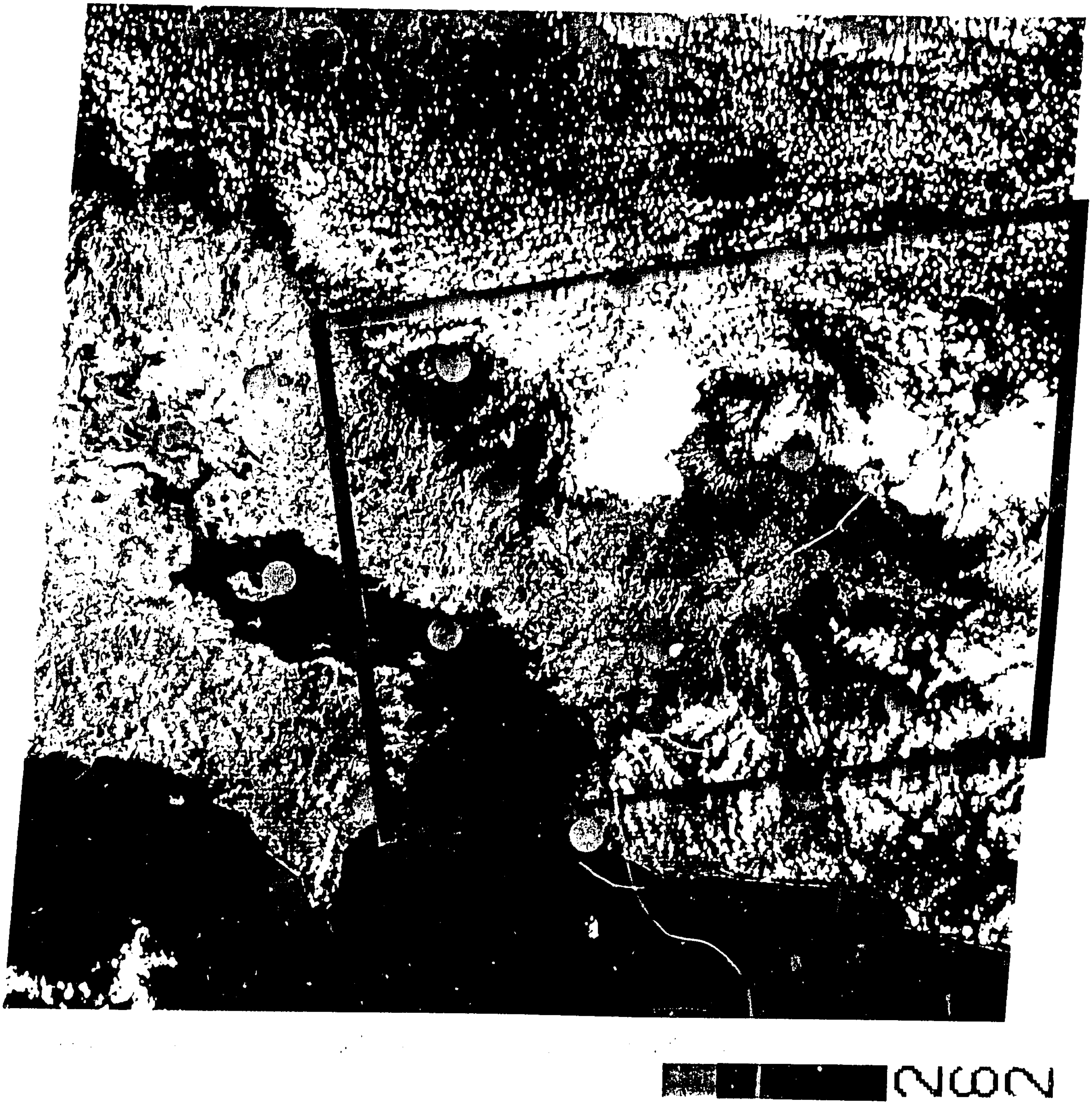
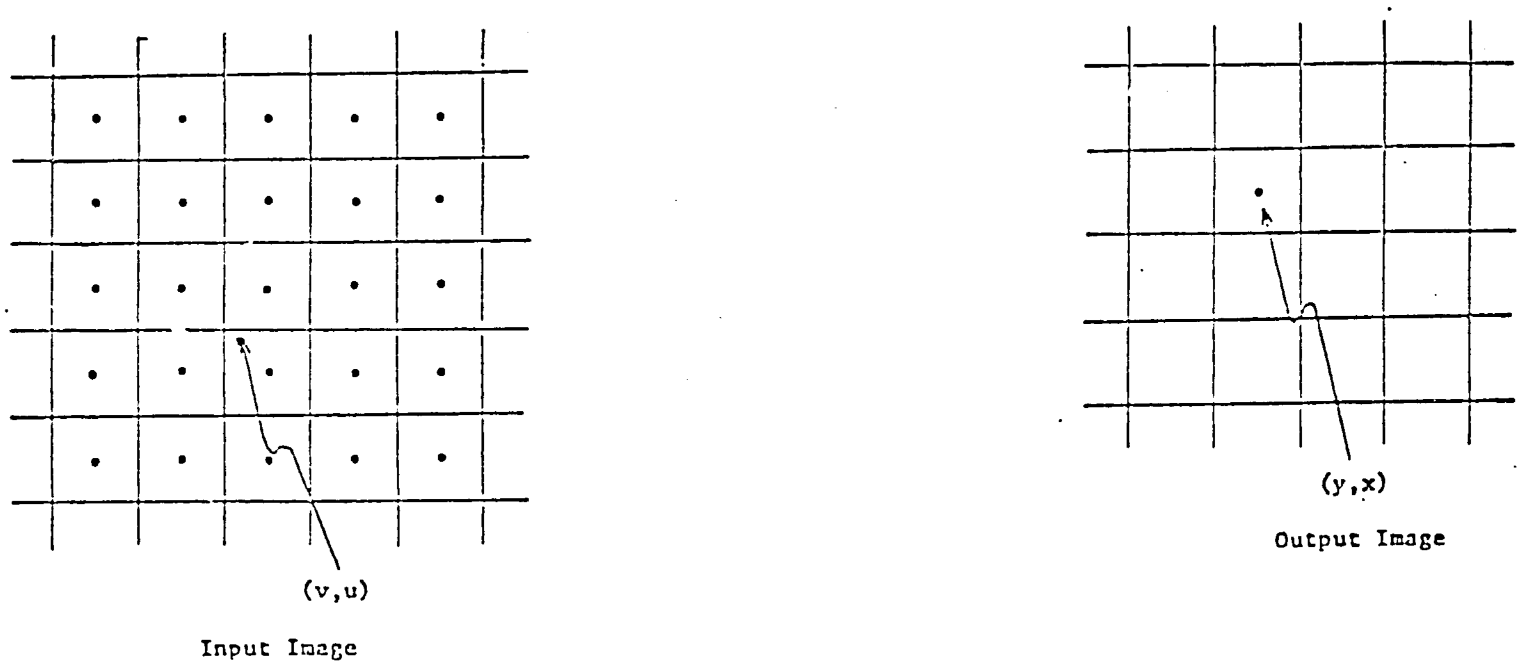


Photo 4-8: Landsat geometric correction control points.

Figure 4-6 illustrates the concept of the nearest neighbor assignment. The pixels in the input and output images are rectangles whose centers have integer-valued coordinates. The point (y,x) in the output image (y and x are integers) is mapped to the point (v,u) in the input image (v and u are rational numbers). The output image pixel at coordinates (y,x) is assigned the intensity value of the input image pixel whose center is nearest to the coordinates (v,u). That is, the intensity value of the rectangular input image pixel containing the point (v,u) is used as the intensity value of the output image pixel (y,x).

Using such a technique, geometrically-corrected classified land cover line-printer maps were produced for the entire project area. Two scales were chosen, 1:50,000 and 1:200,000. These scales correspond with the standard map series produced in Costa Rica by the IGN. Figure 4-7 is an example of a small section of the 1:50,000 Nicoya Peninsula. Compare Figure 4-7 with Figure 4-5 of the 42 spectral classes. The following key applies to the printout in Figure 4-7 as well as to all of the final classified printouts.

Land Cover Class	Symbol
Water, Clouds, Shadow	Blank
Bare Soil	*
Forest	F
Brush	B
Grass 1	1
Grass 2	2
Grass 3	3
Coffee	C
Cane	S
Cut Cane	D
Mangrove	M
Urban 1	X
Urban 2	Y
Urban 3	Z



Assign the intensity of the input pixel nearest to the point (v,u) to the output pixel (y,x).

Figure 4-6: NEAREST NEIGHBOR ASSIGNMENT

Figure 4-7: GEOMETRICALLY CORRECTED LANDSAT LAND COVER CLASSIFICATION

4.2.1.8 Landsat Tabular Statistics

The final task in the computer-assisted classification was the tabulation of the percentage of each land cover class for the 1:200,000 San Jose map area. In addition, the percentage of cover by 1:50,000 quad sheet was also tabulated. This was accomplished by totalling the number of pixels of each land cover class for each desired map. The computer algorithm for this task is called PIXCOUNT.

The first step was to define, by line and column coordinates on the Landsat land cover printout, the boundaries of each quad sheet of interest. Appendix C-7 shows these coordinates. Within these coordinates, the total area (number of pixels) of each of the 14 classes was tabulated. The area of the water, clouds, and shadow class was subtracted from the total area. Percentages of the other 13 classes were calculated based on the remaining total. Appendix C-8 lists these final percentages per map sheet.

4.2.2 Visual Interpretation of Landsat Images

As Landsat CCTs (with minimal cloud cover) were not available for the Limon scene, a computer-assisted land cover classification could not be performed to match the classification performed on the San Jose scene (Section 4.2.1). As a substitute, visual land cover mapping was conducted on the 9 April 1978 Landsat image: the 1978 image was chosen as being the most current. The 1975 and 1978 images had nearly equal amounts of cloud cover (30% and 20%, respectively), although the clouds were distributed differently throughout each image.

The April 1978 Landsat image was enlarged, cut, and attached to the Limon 1:200,000 topographic map transparency. The registration of the geometrically corrected image to the map was nearly exact. The transportation and city locations on the topographic map provided added information for the interpretation of land cover/land use on the image.

A mixture of classification levels (I, II, and III) were used during the interpretation process. For example, grass, brush and seasonal agriculture could not be identified beyond Level I due to the resolution constraints imposed by the Landsat image. Forest was classified only to Level II for the same reason. On the other hand, banana plantations (Level III) could be identified on occasion as a result of their unique field patterns and spectral contrast with non-crop cover classes. In reality, to make a distinction between bananas and other crops on the image, the interpreter must have some prior knowledge of the study area. The same rule applies for identification of cocoa which is commonly shaded by large trees. In this case, prior knowledge of the study area was gained through ground visits and comparison of Landsat images with CIR aerial photographs.

Frequently, a dual classification was assigned to land cover classes on the Landsat image. For example, cocoa, a small tree or large bush, characteristically grows under a forest canopy. If the interpreter believed that cocoa (222) was the dominant use, the classification appeared as 222/41. For abandoned or neglected cocoa plantations, where large trees form a closed canopy and the trees were believed to possess commercial value, the interpreter assigned forest as the dominant use (41/222).

Considering all factors, visual interpretation of tropical land cover classes on Landsat images is a difficult task. The high vigor of all vegetation in the semi-tropical and tropical zones seriously decreases image contrast on which the interpreter heavily relies for distinction between vegetation types.

There are many types of useful information that can, however, be gleaned from visual interpretation of Landsat; e.g., terrain, aspect, general soil and soil moisture, vegetation, and climate. Visual interpretation of Landsat coupled with existing aerial photos and map information formed the basis for development of the biophysical (land management) mapping discussed in Section 4.6).

4.2.3 Aerial Photo Interpretation

The high level of accuracy required in Costa Rica, both in identification and placement of features, could be done only through interpretation of aerial photography. Ground surveys are not only impractical in terms of both cost and time, but many parts of the country are virtually inaccessible from the ground. The use of data from Landsat at the other end of the data spectrum does not provide all desired levels of accuracy and discreteness. In any event, full utilization of Landsat data depends on support from aerial photographic data.

The aerial photo interpretation process had to be carefully planned and executed. To obtain reliable and replicative results required careful preliminary study of the photographs and reconnaissance trips both in light aircraft and on the ground. Using ground transportation, provided by USAID, and working cooperatively with the GOCR professionals, land cover/land use types were identified on the photographs and checked in the field. Continuation of this process during the training phase of tne project assured that both RDA and GOCR professionals involved in the project were in agreement on identifications (Photos 4-9 and 4-10).

The process of photo interpretation was divided among the participating individuals in the project. Some of the interpretation was accomplished by RDA personnel; other parts were done by the Costa Rican professionals in order to provide applications experience in a local situation and to prepare them for lead responsibility in future remote sensing work in Costa Rica.

Photo 4-9: Field training exercise for verification of photo interpreted land cover classes.

Photo 4-10: Ground verification of seasonal cropping patterns near Siquirres, Costa Rica.

The mapping areas (corresponding to IGN 1:50,000 topographic maps) were as follows:

Mapping areas assigned to Costa Rican participants:

Abra	-	total map area
Barba	-	southern one-half of map
Golfo	-	total map area
Matina	-	one flight line from Guapiles to Limon
Naranjo	-	southern one-half of map
Rio Grande	-	total map area

Mapping areas assigned to RDA participants:

Barranca	-	total map area
Tarcoles	-	total map area

Some of the maps were not completed because cloud conditions prohibited full coverage (e.g., Matina).

Conventional methods were followed in the interpretation procedure. Stereo pairs of 1:40,000 CIR photographs were viewed and interpreted with the polygons of land cover/land use being placed on matte finish drafting film overlays. Each polygon was coded in accordance with the classification system. Care was taken to match the polygons at the edges of each photograph to assure that interpreters were consistent in their identifications.

The minimum mapping unit (MMU) for a land cover polygon was designated as four hectares on the 1:50,000 land cover maps (Section 4.5). On the 1:40,000 CIR aerial photography, this MMU is an area of 25 square millimeters. The minimum distance between any two lines of a polygon was designated as two millimeters (80 meters on the ground).

Each interpreter mapped land cover/land use at Level III where possible (see Table 4-1 for a description of classification levels). The Level III urban classification was applied to the larger urban area of San Jose and surrounding cities by the urban geographer from INVU with assistance from an RDA geographer. All interpreters classified perennial agriculture at Level III. However, in some cases, the interpreters were unable to classify the seasonal agriculture beyond Level II, because there were few mature crops in the fields (vegetables, grains) that could be positively identified in January when the land was photographed. Wet season photography was not available to aid in the identification of seasonal crops.

The Level II categories of grass, brush, and tree mixtures were agreed upon by the project participants as a method to classify land into categories that might indicate its relative vegetative condition for grazing use. Category 35 is a transition between the grass-brush continuum and forest, and represents either abandoned pasture land which is reverting back to forest or forest land that has been selectively cut and left idle.

Forests were mapped at Level III by the ITCR, MAG and RDA foresters. The forest Level III classification was based on stand structure components of height and density as follows:

Height Class:

High	=	dominants and co-dominants greater than 25 meters
Medium	=	dominants and co-dominants between 15 and 25 meters
Low	=	dominants and co-dominants less than 15 meters

Density Class:

High	=	dominants and co-dominants greater than 80% crown cover
Medium	=	dominants and co-dominants between 50% and 80% crown cover
Low	=	dominants and co-dominants less than 50% crown cover

Limited access to forest lands prevented thorough ground verification of the Level III forest classification. For this reason, the forest Level III classifications for the Pilot Project are estimates subject to revision through field verification.

4.3 Ancillary Map Data Compilation

A major goal of the Pilot Project was to produce information on several related characteristics of land, in addition to current land cover (e.g., drainage, soils, slope, geology) which would enhance the natural resources inventory and contribute to the development of a geographic based information system. In keeping with that goal, map overlays of these land attributes were produced at IGN national map scales (Section 4.5).

Data for some of the maps -- soils, slope, and geology -- came in published or draft form from Costa Rican sources; some had to be modified to match project map scales. Two others - drainage and watersheds -- are original maps prepared by RDA cartographers.

4.3.1 Drainage and Watershed Boundaries

Detailed maps of drainage patterns support spatial data on the information regarding soils, geomorphology, geology, geohydrology, physiology, and ecology of an area. In addition, such maps are a prerequisite to construction of accurate and detailed watershed maps.

Using the 1:50,000 standard topographic quadrangle maps of Costa Rica published by the IGN, detailed drainage patterns were drawn. The drainage was extended upstream far beyond the limits of the recognized intermittent streams to include all large gullies and rills. Inspection of patterns and textures of these drainages would allow inference of lithology, structure, and geomorphologic features of the area.

Once the drainage maps had been prepared, the watersheds could be delineated. Determination of watershed boundaries, or in fact, watershed size, is essentially an arbitrary process. The definition of watershed, from the American Geological Institute, is "the area contained within a drainage divide above a specified point on a stream". The ambiguity in this definition is the word "specified". A watershed may be as large as the Amazon Basin or as small as one hectare. Ideally, one would choose a watershed size based on the purpose for its delineation. Since, in Costa Rica, we are interested in land management of relatively small units, the watershed size should be on the same order. Watersheds of approximately 15-50 square kilometers were accordingly delineated. The exact size depended largely on the specific characteristics of the stream system. Natural confluences and breaks in stream pattern were used as guidance.

Each delimited watershed was assigned the name of its primary stream. In cases where a major stream, such as the Rio Tarcoles, would dominate several watersheds, a name/number system was used. Using the Tarcoles as an example, the watershed closest to its mouth was labelled "Rio Tarcoles I", the next watershed upstream was labelled "Rio Tarcoles II," etc.

The main purpose of watershed delineation is to simplify prediction of the effects of any environmental change on the water quality or quantity of an area. Any change in water quality initiated in a particular watershed will affect the quality of all watersheds downstream. Likewise, the quality or quantity of water entering a particular watershed is influenced by all the watersheds upstream from it. Figure 4-8 shows the priority relationships between all of the watersheds comprising the Rio Grande de Tarcoles, and which fall in total or in part on the map sheets prepared for this project. Figures 4-9 and 4-10 are examples of portions of drainage and watershed maps from the Barranca map sheet.

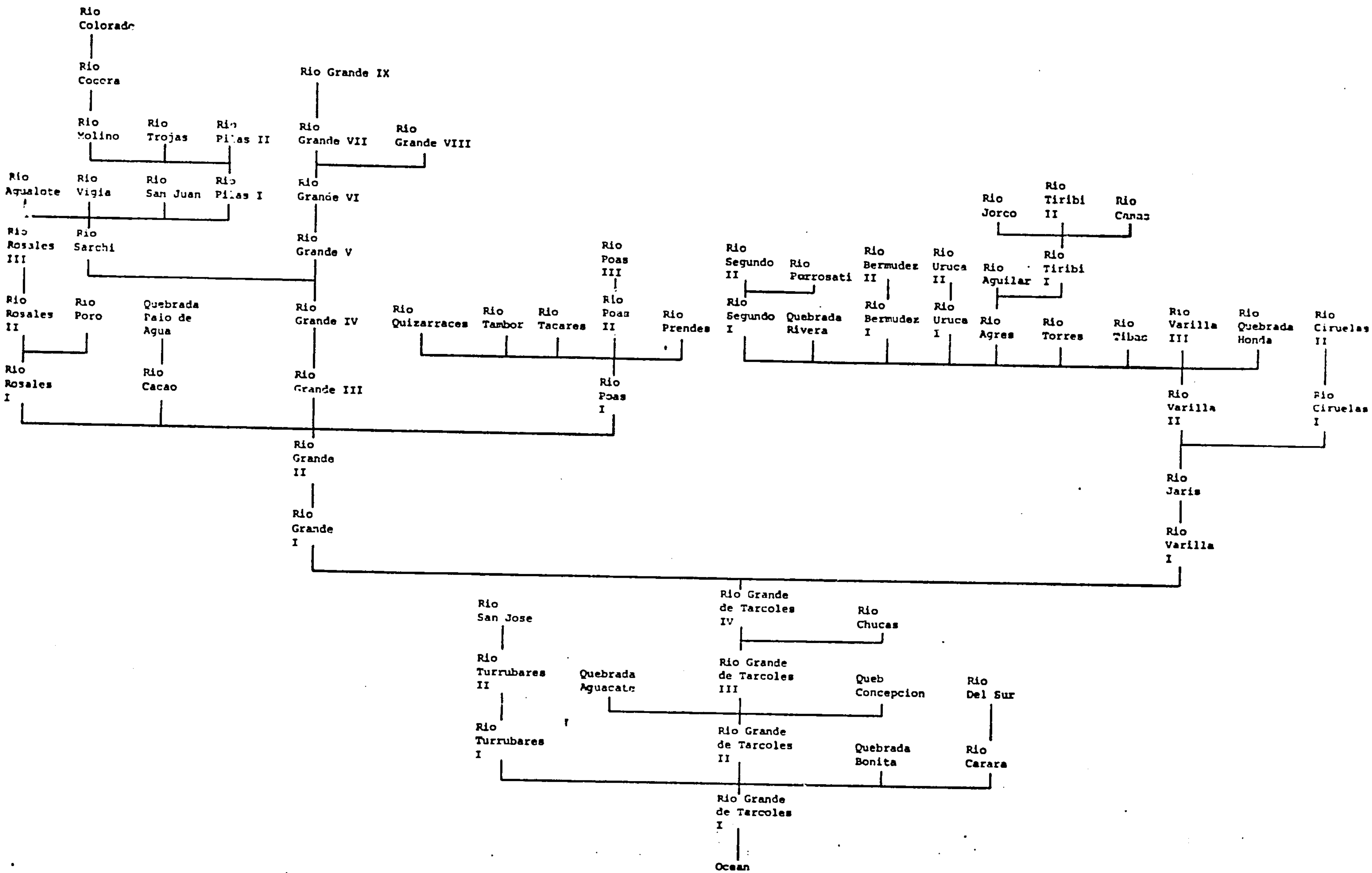


Figure 4-8: DRAINAGE AND WATERSHED SYSTEM FOR THE RIO GRANDE DE TARCOLES

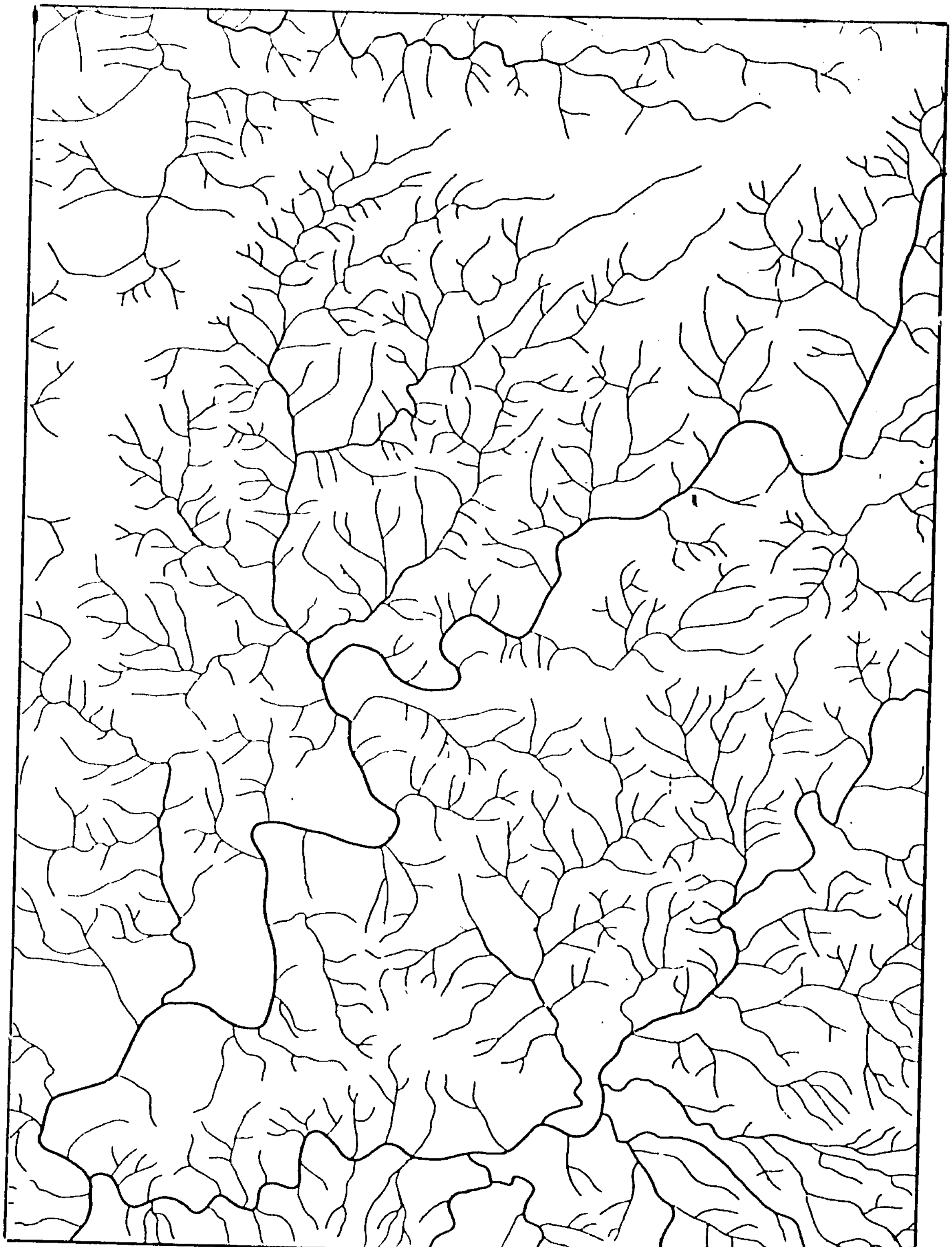


Figure 4-9: EXAMPLE OF THE DRAINAGE OVERLAY FOR A PORTION OF THE BARRANCA 1:50,000 MAP SHEET

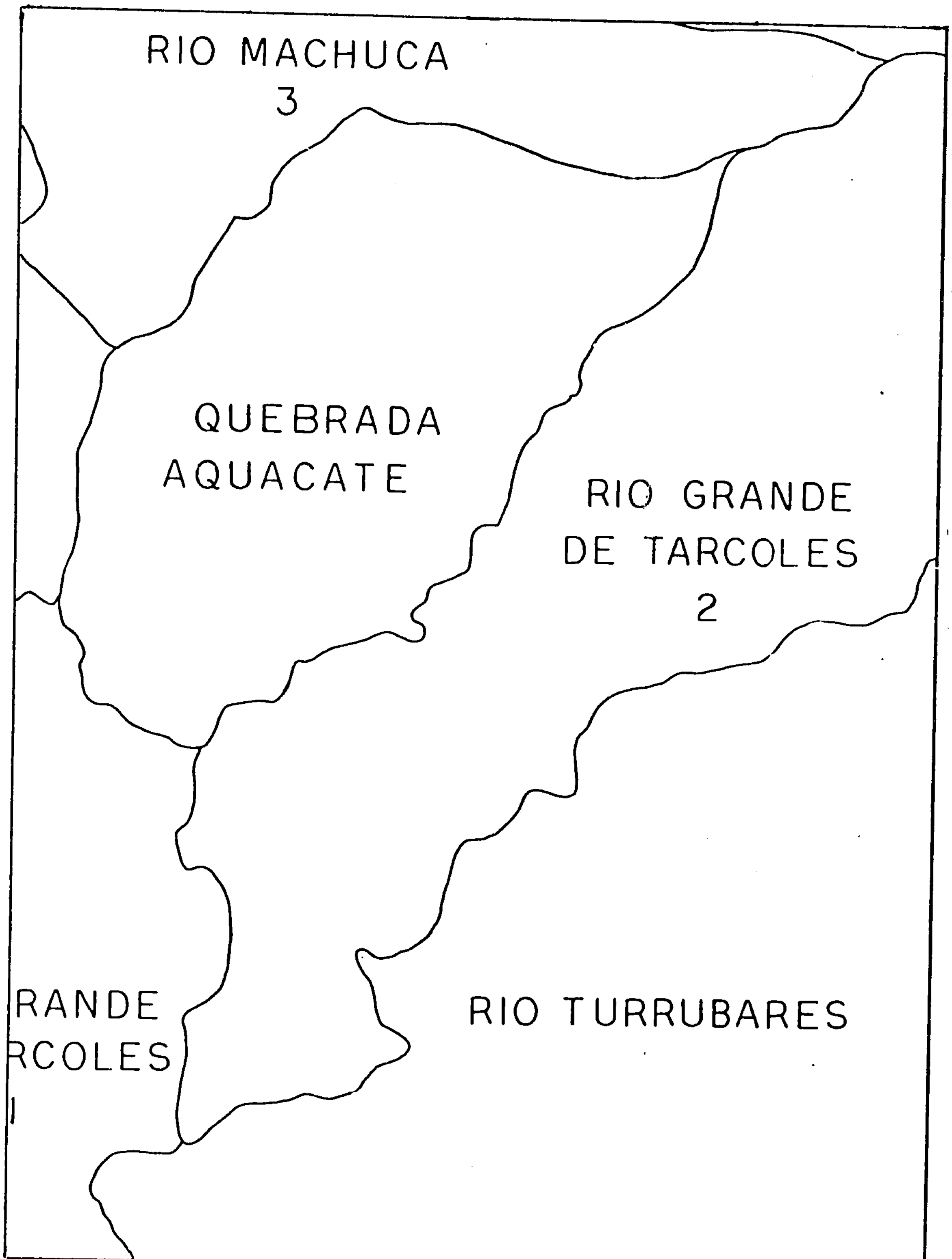


Figure 4-10: EXAMPLE OF THE WATERSHED OVERLAY FOR A PORTION OF THE BARRANCA 1:50,000 MAP SHEET

4.3.2 Slope Maps

RDA analysts planned from the beginning of the Pilot Project to include slope maps in the thematic series. Fortunately, IGN initiated a project to define slope classes on their 1:50,000 quadrangle sheets. Upon conferring, they coordinated their slope mapping program with the Pilot Project map coverage and assigned priority to those map sheets. The slope maps were produced by measuring distances between contour lines from the topographic map sheets and aggregating areas into four major slope classes; 0 to 9 degrees, 10 to 19 degrees, 20 to 29 degrees, and those areas having slopes greater than 30 degrees. These maps were checked by RDA and final maps were prepared through a cartographic process (Section 4-4). The final maps display the four slope classes as levels of gray (see Figure 4-11). These slope maps can be used in conjunction with land cover, geology, and other ancillary data to form the basis of many primary assessments of land use patterns associated with slopes, slopes associated with soils and geology, etc.

4.3.3 Soils

In 1978, a draft of a Costa Rican soil association map was made available to the RDA team. This map was produced through the Office of Sectorial Planning for Agriculture and was produced by Samuel Perez, Alfredo Alvarado, and Elizabeth Ramirez in collaboration with Dr. Ellis G. Knox. This map, at a nominal scale of 1:200,000, has been produced for the entire country although at this time the final map has not been completely field checked and is not officially in publication. However, it was used for both the 1:200,000 mapping and was enlarged to 1:50,000 to be compatible with the thematic map series (Section 4.5). Although not containing levels of discreteness associated with primary mapping at 1:50,000, these maps have been valuable especially after refining the boundaries by using geologic and

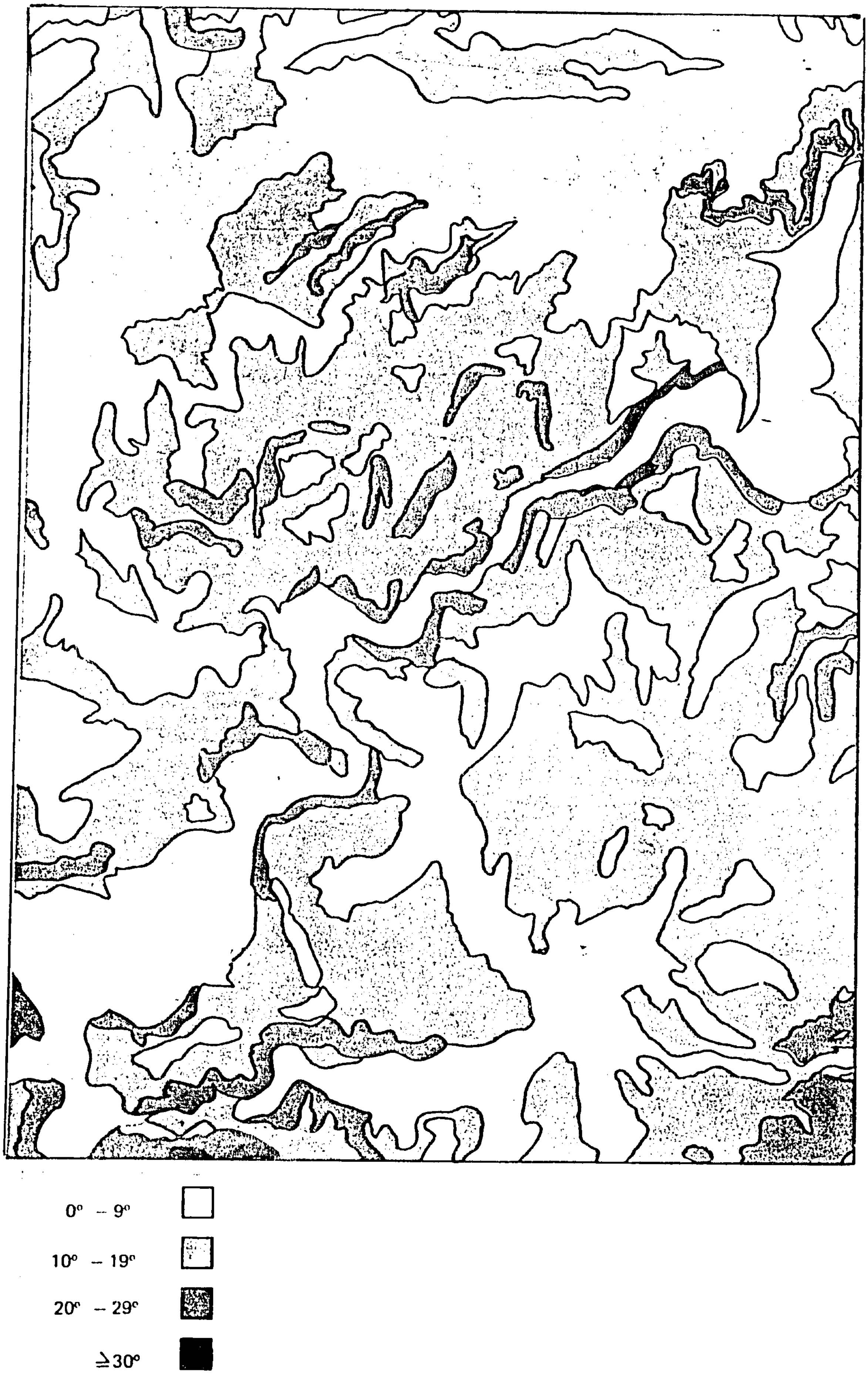


Figure 4-11: EXAMPLE OF THE SLOPE OVERLAY FOR A PORTION OF THE 1:50,000 BARRANCA MAP SHEET

slope maps as support data. A condensed legend showing the applicable soil associations appears in Appendix D-1. An example of the soils mapping is shown in Figure 4-12, taken from the 1:50,000 Barranca map sheet.

4.3.4 Geology

The geologic maps prepared for the Pilot Project came from a variety of sources. The 1:200,000 overlays were obtained from the geologic map of Costa Rica (preliminary edition of 1968) at an original scale of 1:700,000. This map was then enlarged to a 1:200,000 map base. Although the map was not intended to be used at this scale, it did provide important information in the absence of other data. Also used in regional mapping was the geologic map of the Central Valley at the scale of 1:150,000 produced in 1968. Two 1:50,000 quadrangle maps were used, one for Barranca produced in 1967 through the Ministry of Industry and Commerce and printed by the IGN, and one for Rio Grande produced in 1970, authored by Rolando Castillo. (The two 1:50,000 geologic maps are actually lithologic in type since structure was omitted from both.) The legends for all these maps are included in Appendices D-2 through D-4. An example of the 1:50,000 mapping is shown in Figure 4-13.

4.3.5 Ecological

The Ecological Map of Costa Rica, by J. A. Tosi, Jr., was enlarged from 1:750,000 scale to the 1:200,000 base map scale to aid in the preparation of the land management map. The ecological or life zones are outward expressions of macro climatic forces: precipitation, evapotranspiration and biotemperature. Each zone has a characteristic vegetative, soil and hydrologic component, among other attributes, as dictated by the three climatic variables. For these reasons, the ecological

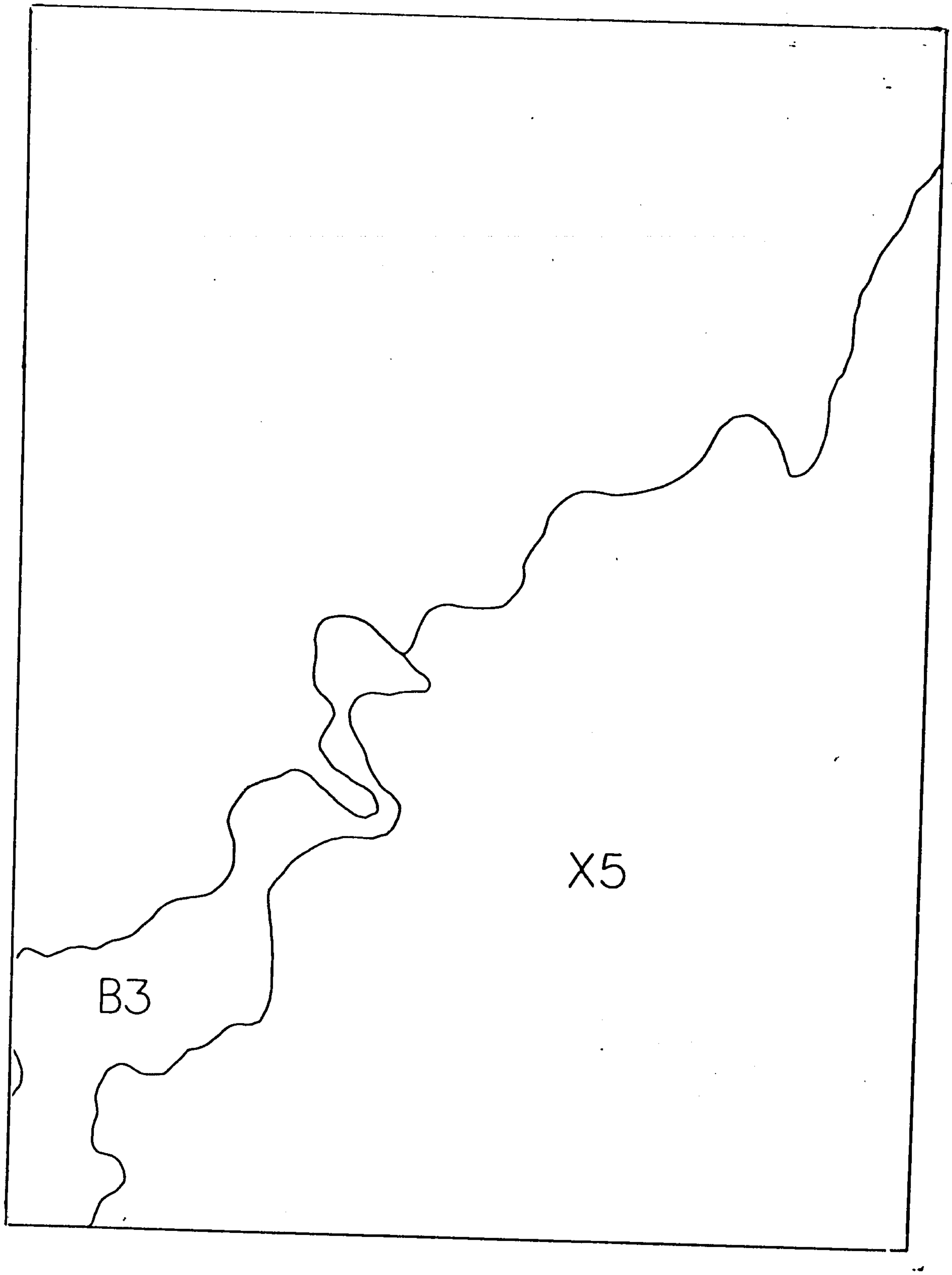


Figure 4-12: EXAMPLE OF THE SOILS OVERLAY FOR A PORTION OF THE 1:50,000 BARRANCA MAP SHEET

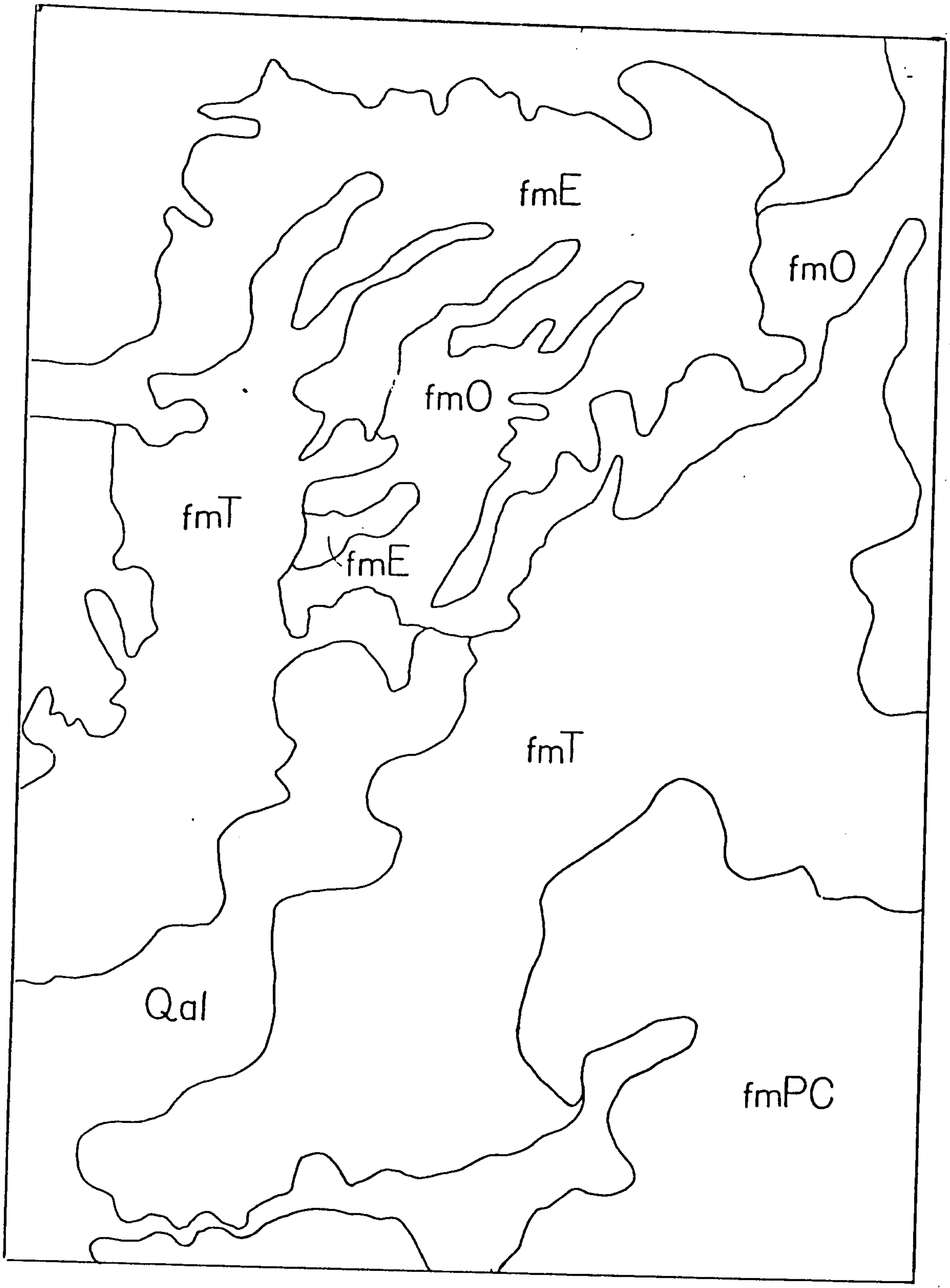


Figure 4-13: EXAMPLE OF THE GEOLOGIC OVERLAY FOR A PORTION OF THE 1:50,000 BARRANCA MAP SHEET

map was valuable in the development of the biophysical classification and preparation of the land management map. The value of the land management map itself is discussed in Section 4.6. A key to the 1:200,000 ecological map is found in Appendix D-5. Further explanation is found in "Forest Environments in Tropical Life Zones," by Holdridge, et. al. (14).

4.3.6 Topographic Separates

Separates, which are clear transparent overlays of three themes on standard IGN topographic maps, were furnished by the IGN for use in the mapping program. These separates include cultural features, drainage, and topographic contours. They fulfilled a variety of uses including the accurate registration of both aerial photographic data and satellite data during the mapping process. The one square kilometer grid cell (Lambert projection) on one of the overlays provided both sample and count units for the sampling techniques and measurements performed in Section 5.1 and 5.2.

4.4 Map Production

Land cover/land use polygons on the photo overlays were transferred to the base maps through the use of optical devices which matched the scale of the photography (1:40,000) to that of the maps (1:50,000). This procedure was necessary to prepare the land cover data for map production.

To achieve maximum durability and usability of the products of the Pilot Project, full production line methods were followed in the preparation of all maps. Thus, instead of simply providing pen and ink drawings, all maps were made into what printers refer to as separation sheets. These sheets of clear plastic overlays, each carefully registered to their mates in a given series of overlays, were prepared by using the scribing method. In this process, multi-coated sheets of stable-based plastic material have point and line features plus written material etched into their surface, thus creating, in effect, a photographic negative.

All that was required to employ these in a full-color printing process was to convert each of these "scribe-coats" to a printing plate, a routine printing process. An agency, such as the IGN, could easily make production printing runs of all the maps in the series provided by the project. All were registered to stable-base drafting film base maps at the same scales they regularly published by IGN. With an appropriate legend and annotation, each map can serve either as a "stand-alone" piece or be incorporated into a series for each of the quadrangles mapped.

4.4.1 Data Transfer to Base Maps

Two types of camera-lucida instruments were employed to transfer photo interpreted land cover boundaries to the 1:50,000 IGN base maps. The first, a Vertical Sketchmaster (Photo 4-11) is a device that employs a full-silvered and a semi-transparent or semi-silvered mirror to superimpose photo and map images. The

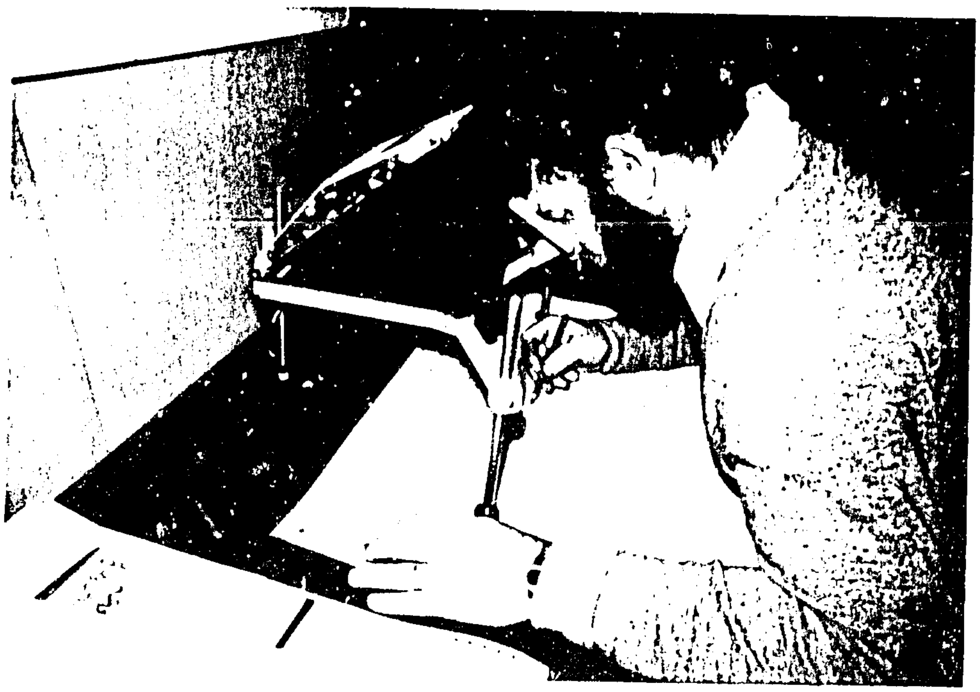


Photo 4-11: Operator transferring photo interpreted detail to 1:50,000 base map with a Vertical Sketchmaster.

operator places a contact print or positive photo transparency face up on the platform base under a large, full-silvered mirror. Photo images are reflected from the large mirror to a semi-silvered mirror in the eye piece housing. The platform base was cut out of the Vertical Sketchmaster and replaced with a frosted translucent glass plate to extend the use of the instrument to photo transparencies. A desk lamp was projected up through the glass plate and transparency. When the viewer looks into the eyepiece, the semi-transparent mirror provides a monocular view of the reflected photo image to the base map simultaneously. After the base map is secured in position with masking tape, the Sketchmaster must be moved around over the base map with the leg screws readjusted each time that a different portion of the photo is transferred.

The Bausch and Lomb Zoom Transfer Scope (ZTS) is a more sophisticated instrument that, in contrast to most camera-lucida instruments, provides binocular viewing of both the photo image and base map. The ZTS provides variable magnification, image rotation, and up to two times an amorphic scale change. The latter makes the instrument most useful for plotting land cover data in which the scale change is inherently different in two directions. The illumination controls allow the viewer to see the image (vertical plane) or the map (horizontal plane) or both at one time.

Natural and man-made features such as ridge tops, water courses, shorelines and road, aid the registration of the photo data to the topographic base map. The speed and accuracy of transfer improves as the viewer gains experience with either instrument.

4.4.2 Separation Sheet Preparation

Modern instruments were employed to compile all of the thematic data into composite maps at scales of 1:50,000 and 1:200,000. Stable-base drafting materials, drafting film and scribe coat were used to maintain registration. Separation sheets were prepared for printing and reproduction was conducted under controlled laboratory conditions.

All of the separation sheets were designed to overlie a topographic base map, which were reproduced in a brown tone through the use of an interposed screen.

4.4.2.1 Scribing Point and Line Features

Map artwork can be prepared using positive or negative form. Using the positive form, the desired lines and symbols are applied by the draftsman, as in a pen and ink drawing. In negative form, desired lines and symbols are removed by scribing; by photo transfer they become positive. This scribing method was used for the project because: 1) uniformly high line quality could be maintained; 2) stability was insured; 3) the separation negatives would be compatible with IGN maps and mapping procedures; and 4) the method is recommended by professional printers for production mapping operations.

In scribing, the desired lines were produced by removing material from a scribe coat. This scribe coat consists of a sheet of clear plastic as a base to which a translucent coating had been applied. This coating is translucent so that the scribe coat may be placed on a light table for scribing, but it is also actinically opaque to allow only those wavelengths of light through which will not affect sensitized material. Lines were cut in this coating using a K & E rigid graver with a .010 point (Photo 4-12).

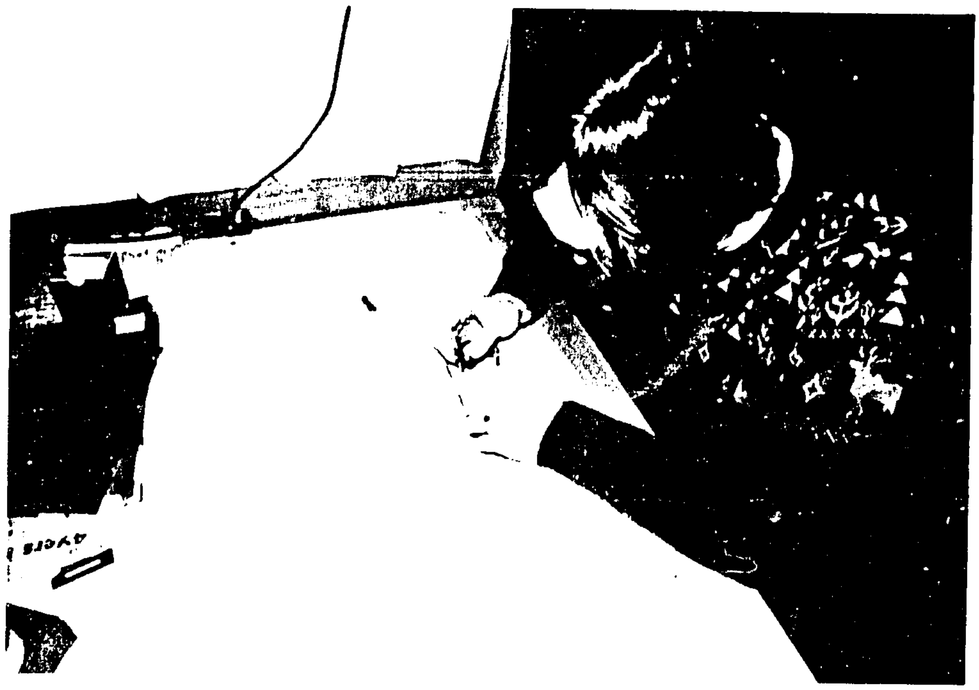


Photo 4-12: Scribing and lettering on the scribe coat in preparation for map reproduction.

When scribing, several methods were used to transfer the data to the scribe coat. The lines to be scribed can be made to appear in the emulsion on the scribing surface. This produces a scribe guide. A second technique is to trace on a light table from the compilation sheet below the scribe coat. This method, which eliminates the need for a scribe guide, was used to produce the satellite land cover maps. After cover types were aggregated on the line printer maps, these maps were placed under a scribe coat on the light table and scribed directly. A third technique was the transfer the data to the scribe coat in pencil and then scribe the lines. This was employed for the soil, geology, drainage, watershed, and land cover maps. Each map was then labelled with the appropriate code numbers and names using the K & E graver and a lettering template.

4.4.2.2 "Peelcoat" for Areal Features

A process similar to scribing, but used for areal rather than linear phenomena, was used to produce the Landsat land cover maps. Class boundaries were photographically printed onto the opaque (red in color) surface of a material called "peelcoat". Using these boundary lines, each land cover class (10 in all) was peeled from a separate peelcoat sheet (Photo 4-13). In the photo laboratory, all peelcoats were interposed to produce a display of all ten land cover classes on one clear positive overlay. Slope maps (Figure 4-11) were also prepared by the peelcoat process.

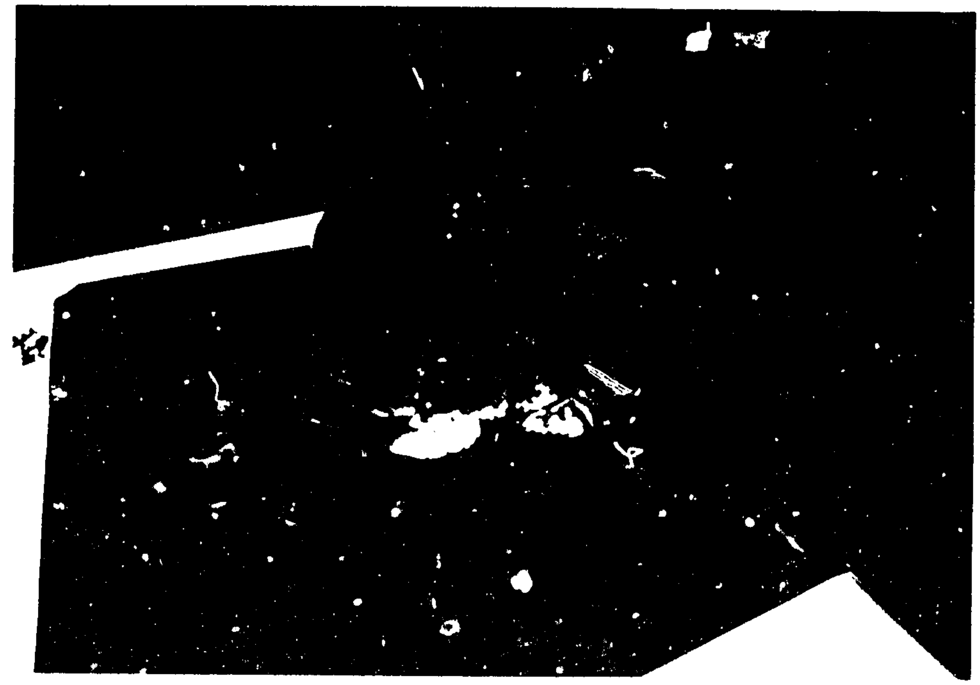


Photo 4-13: Landsat land cover "peelcoat" being prepared for map reproduction.

4.5 Thematic Mapping and Geographic Information Systems

At the beginning of this project, the need for a geographic information system (GIS) for natural resources was evident. There are two basic systems. The first is a manual system which involves the use of conventional cartographic map bases and relies upon the storage and comparison of the data through techniques such as thematic mapping. The second and more recent system utilizes a computer for storage, retrieval, and manipulation of the information. The digital GIS allows the rapid reformatting of data to different scales, and can be more efficient in the manipulation of variables. However, the data are in no way directly enhanced by being entered into a computer, and such a system may be more costly than its manual predecessor. The IBM 370/115 computer currently available in Costa Rica has inadequate storage capacity to handle the large amounts of data contained in one Landsat scene. There is currently no available software in Costa Rica to process Landsat daa, and there are only a few trained technicians familiar with the Landsat computer processing format. Accordingly, Costa Rica must rely at present on U. S. sources for complete Landsat digital processing.

Whether or not a computerized information system should be eventually adopted by the GOCR is a decision that must be weighed on the basis of recommendations of this project and others which examine specific aspects of the resource sector. The thematic maps presented here, combining remote sensing and ancillary data at common topographic map scales for regional and local applications, are ideally suited for phasing into a digitized system.

The manual thematic overlay system of storing, retrieving, and analyzing data is the precursor to the computerized geographic information systems that have been adopted by various natural resource agencies in the United States and other developed countries (15). The methods and objectives of a manual or computerized GIS are the same. Computer systems offer faster processing, greater versatility, and more options in the output products. However, storing, manipulating, and retrieving data by computer are complex tasks, warranting technical considerations beyond the scope of this report.

There are some distinct advantages of establishing a manual GIS for natural resource data in Costa Rica. These include the following:

1. A manual GIS does not require a major capital or technical investment to operate and maintain at a time when such investment decisions have not been fully evaluated or accepted as a desired course of action.

2. A manual GIS does not require any additional human or technical facilities to operate and maintain beyond those presently available in Costa Rica.

3. Manual data base development and cartographic display of natural resource components are a prerequisite to setting up a computerized GIS if such a system becomes desirable at some later date.

4. A manual GIS provides an improved method of data storage, retrieval, and analysis over that currently available from dispersed natural resource map data at various scales.

Some disadvantages of a manual GIS are:

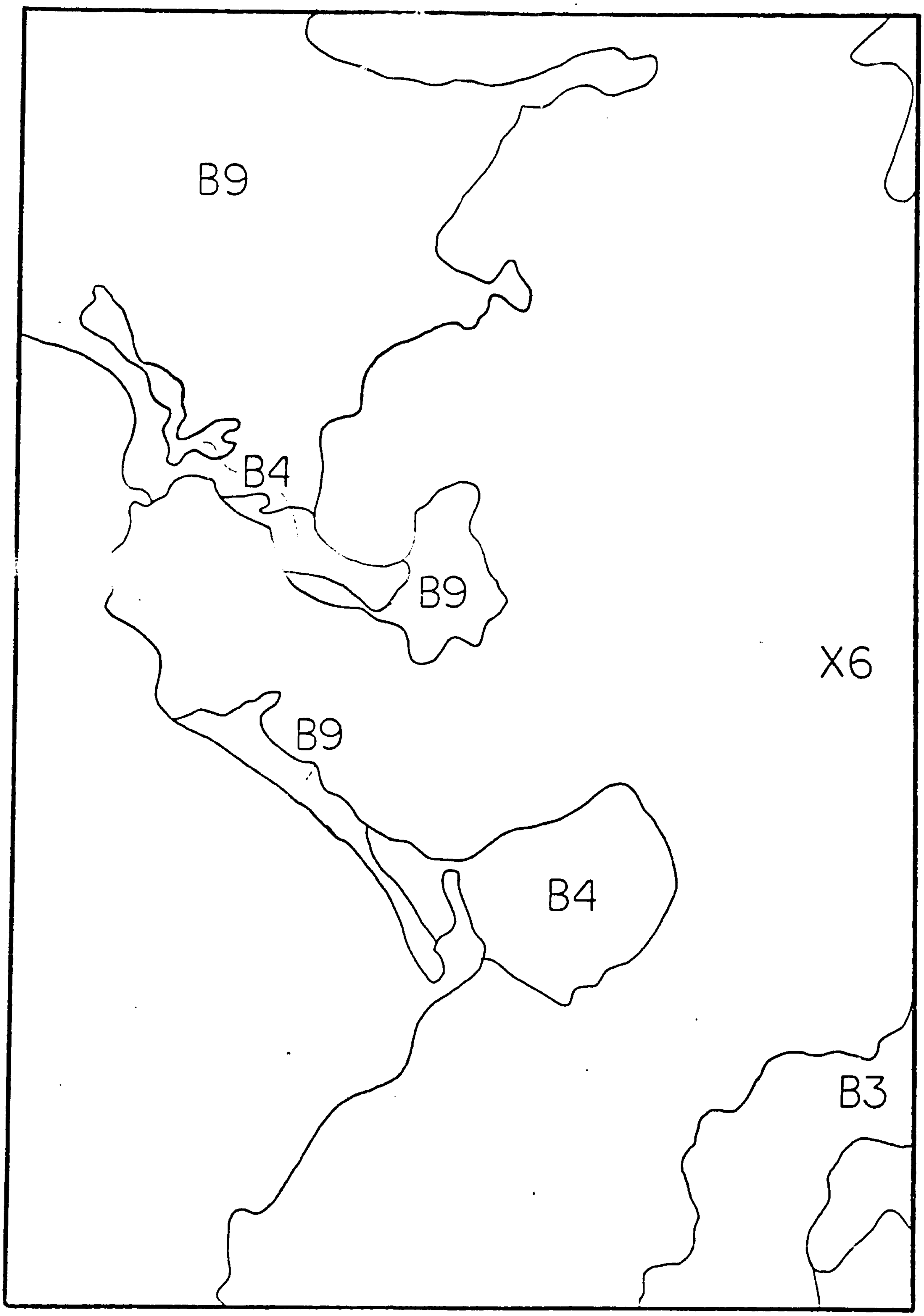
1. The storage of natural resource data on maps is bulky and the maps tend to deteriorate with extensive use. Duplicates may need to be reproduced and maps must be updated and reproduced periodically.

2. Visible map features may be obscured when attempting to overlay more than two maps at one time.

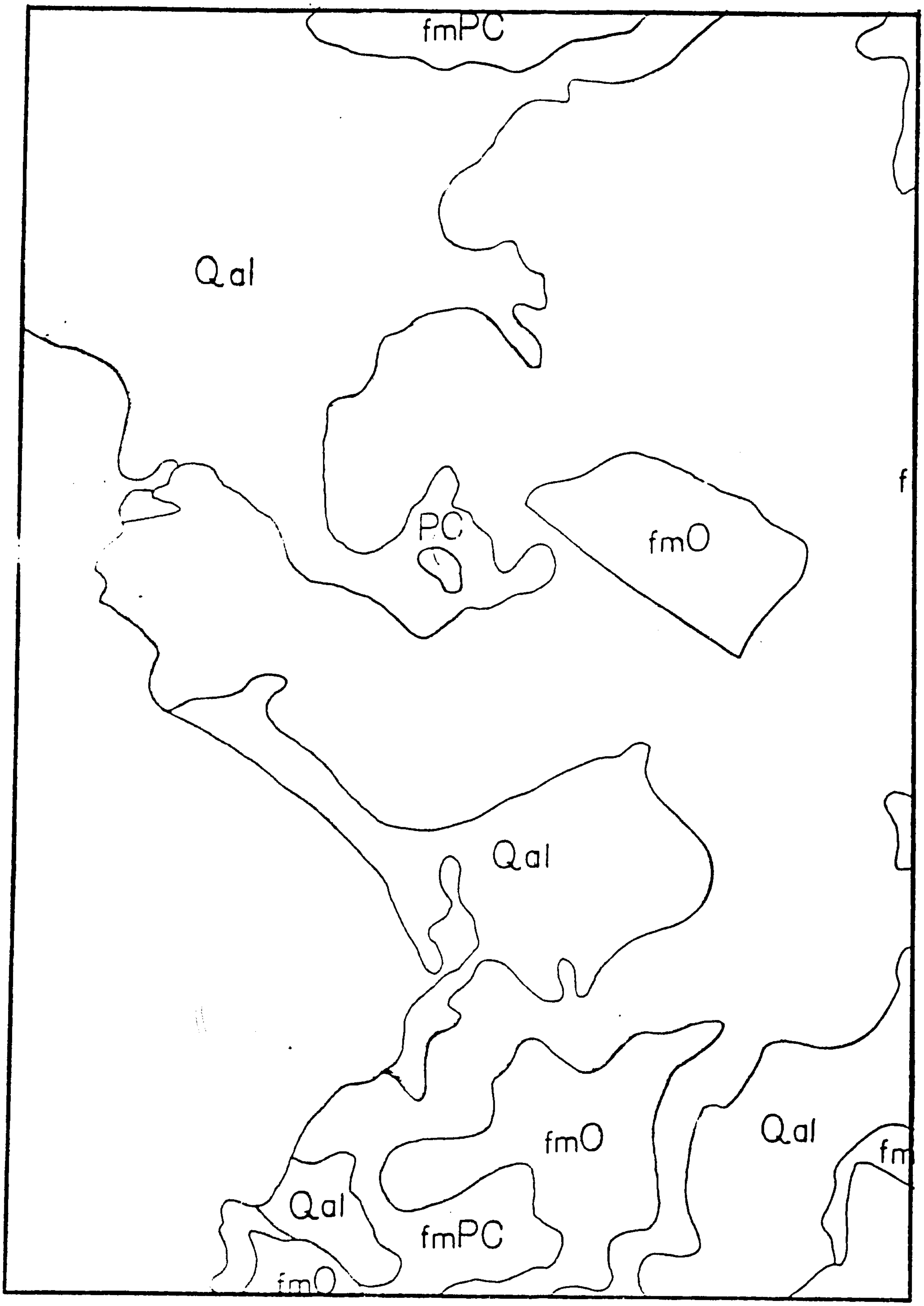
The thematic maps prepared for the Pilot Project have a defined set of characteristics. Popularized first in the United States by Ian McHarg in his book Design with Nature (16), they display the location and spatial distribution (at desired scales) of an individual natural resource attribute (a "theme") or a combination of related resource attributes. The maps are usually in the form of transparent overlays displaying color codes, grey tones, or symbols corresponding to a parameter or value assigned to the resource. The basic principal of the thematic mapping approach is to combine individual and complementary natural resource data into a composite theme where natural or artificially assigned resource attributes become visible and apparent to the map user. The type and quantity of resource themes depend on the specific problem and associated information needs. In Costa Rica, there is a variety of natural resource data available that have been compiled and reproduced as thematic overlays at IGN national map scales for this project. As new data become available and maps are produced at national scales, the number of themes and possible combination of data types can yield information useful for specific resource program applications. Figure 4-14 is a sample portion of the thematic map display on the Barranca 1:50,000 base map. Used individually, these maps have intrinsic value for their particular topic: used interactively and in consort with one another and with the land cover/land use maps, they become synergistic. Using the topographic map as a base, any combination of resource overlays can be viewed. The intention is not to view all of the overlays at one time; rather, two or three themes are usually examined.

Figure 4-15 shows the specific location and coverage of the Pilot Project study area by thematic maps. These maps represent the current land cover and renewable resources inventory for the Pilot Project. Compare this figure with Figure 2-1; the proposed Pilot Project study area. The actual inventory coverage is larger than the 10,000 square kilometers originally proposed for this project. Land cover was mapped for approximately 2,750 square kilometers by the photo interpreters. Computer-assisted Landsat land cover classification for the San Jose 1:200,000 map covers approximately 10,000 square kilometers. Visual land cover mapping performed for the Limon 1:200,000 map covers an estimated 3,500 square kilometers.

The utility of the thematic maps and the geographic based information system can be demonstrated in several ways. Section 5.0 discusses various analyses and resources monitoring

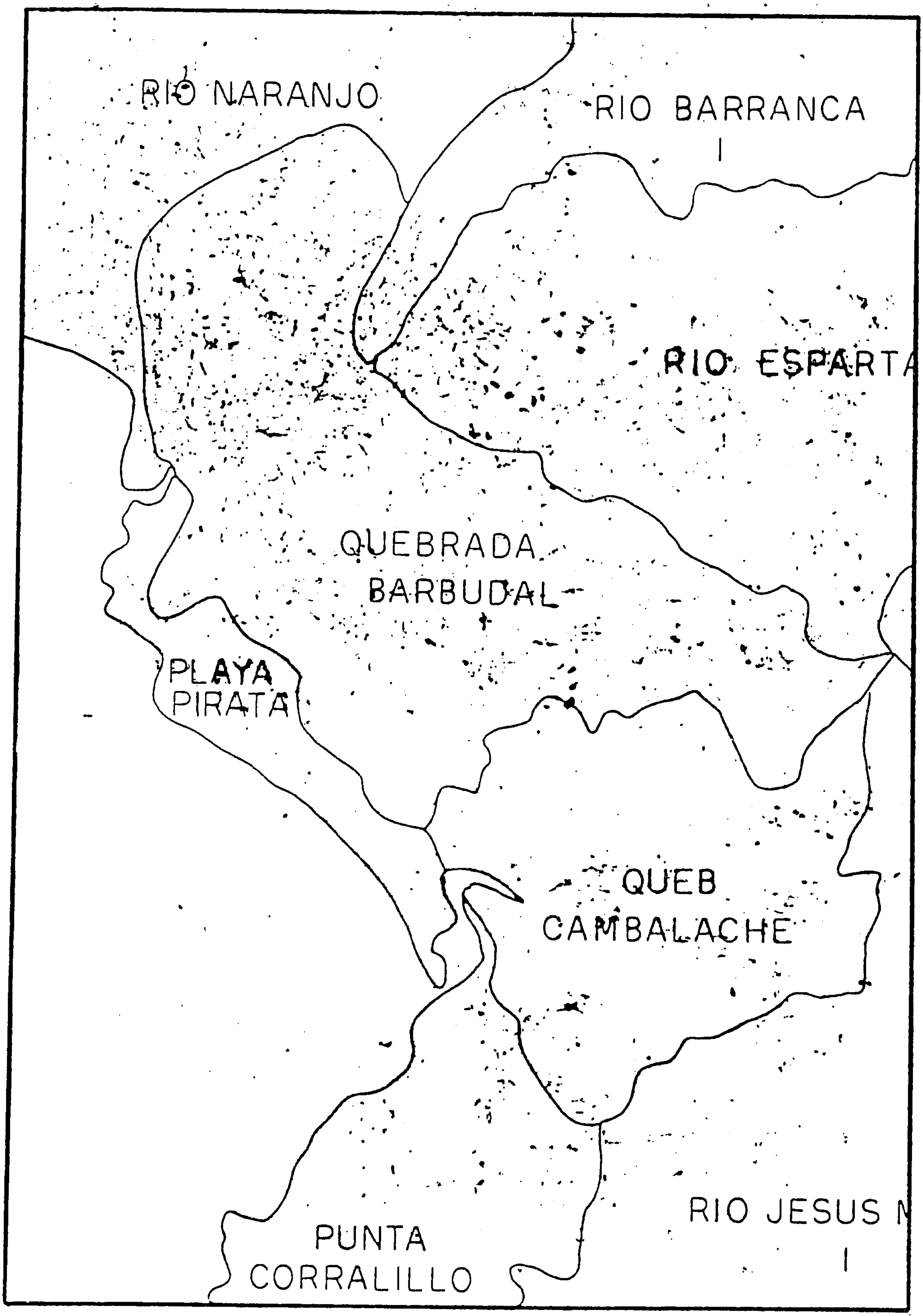


SOILS



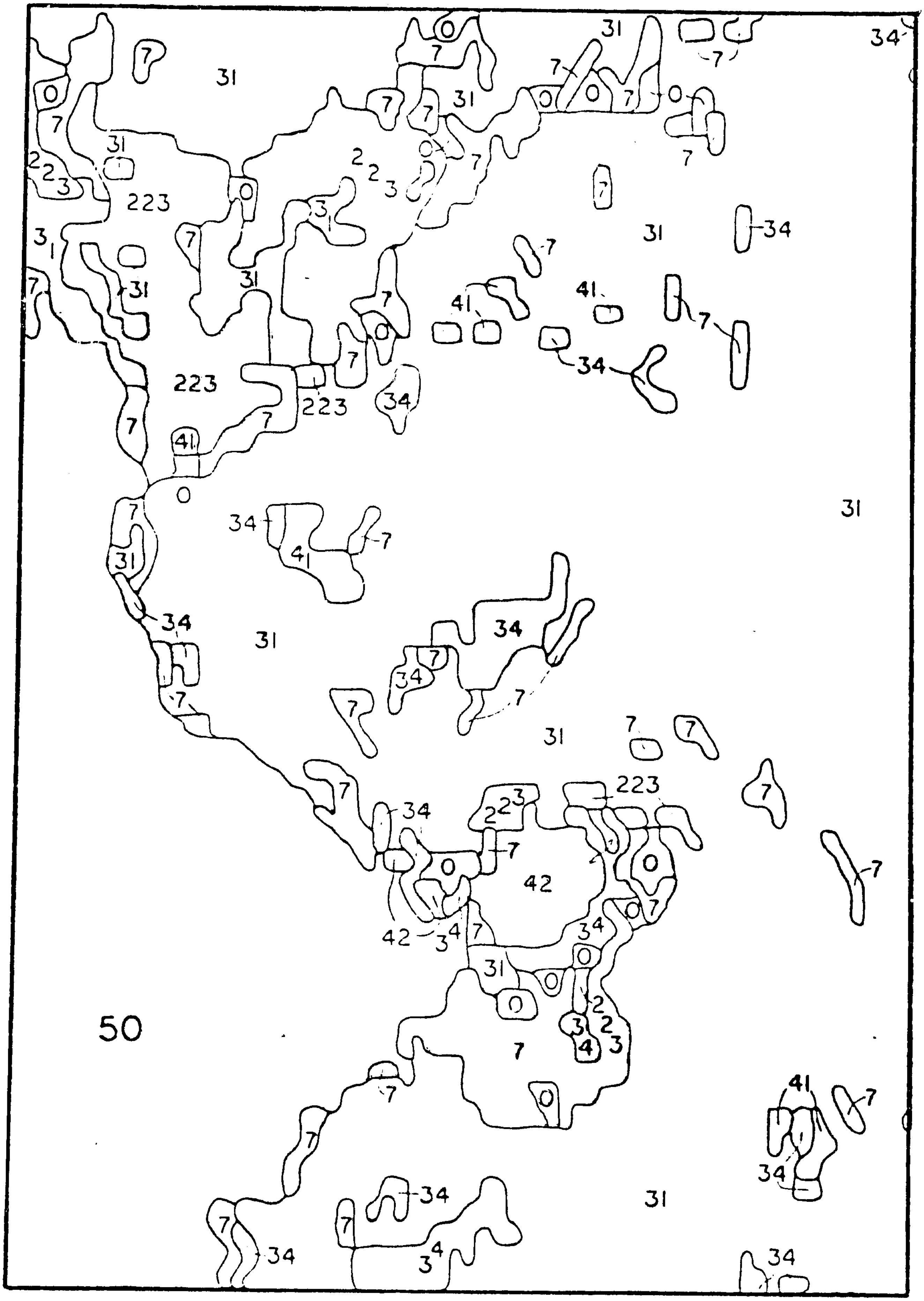
GEOLOGY

DRAINAGE

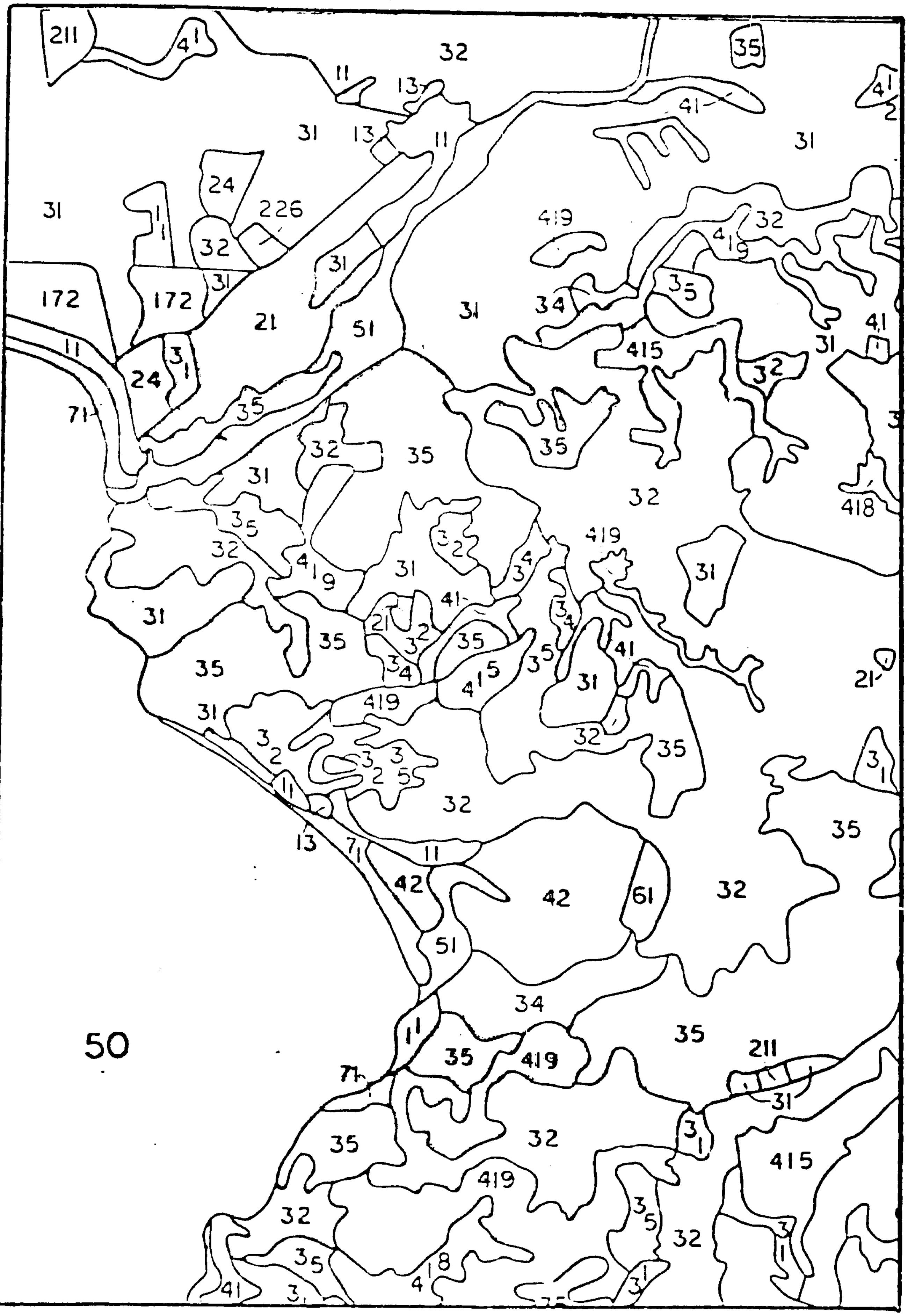

RIO NARANJO
RIO BARRANCA
RIO ESPARTA
QUEBRADA
BARBUDAL
PLAYA
PIRATA
QUEB
CAMBALACHE
RIO JESUS M
PUNTA
CORRALILLO

WATERSHED

SLOPE



LANDCOVER
(Derived from Landsat Data)



LANDCOVER

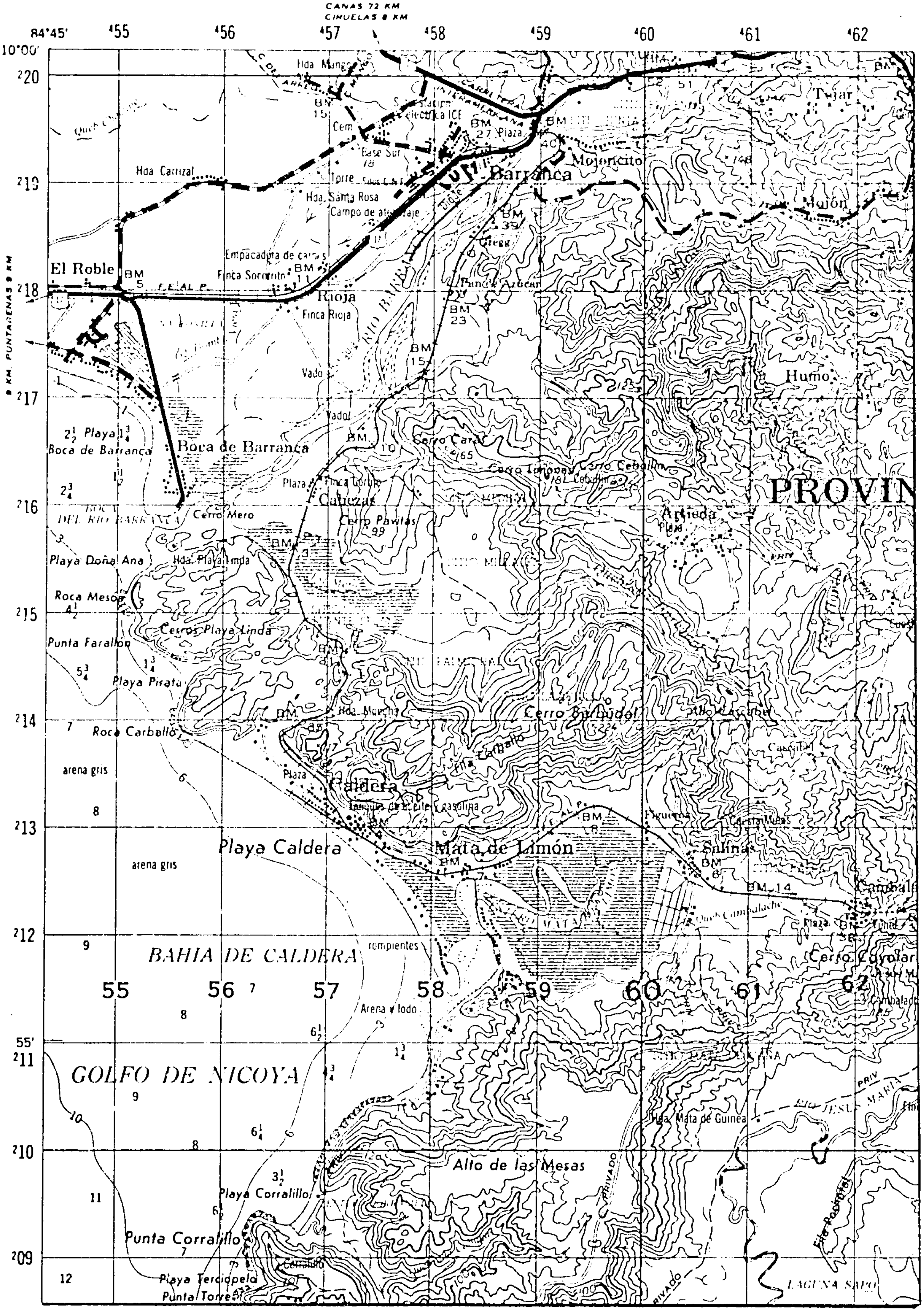


Figure 4-14: THEMATIC MAP DISPLAY: BASE MAP

(Barranca Map Sheet, Costa Rica)

1:200,000 Scale Maps:

A San Jose

B Limon*

1:50,000 Scale Maps:

1 Naranjo

2 Barba

3 Golfo

4 Barranca

5 Rio Grande

6 Abra

7 Tarcoles

8 Matina

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* Includes a visual Landsat land cover classification only.

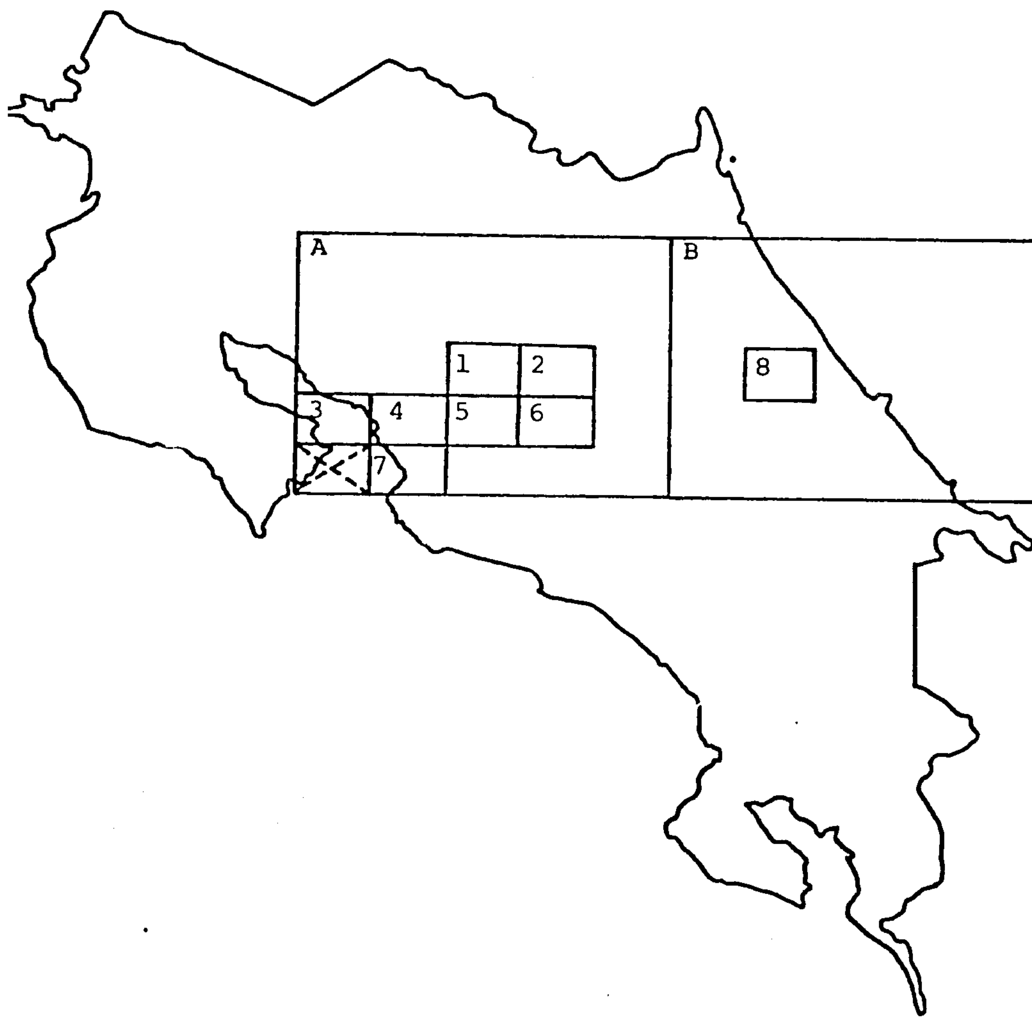


Figure 4-15: LAND COVER AND RENEWABLE RESOURCES INVENTORY: THEMATIC MAP COVERAGE OF THE PILOT PROJECT STUDY AREA

techniques applied through the use of this system. Secton 4.6 discusses the use of selected map themes to develop a biophysical classification and land management map.

These maps and analyses performed provide information of sufficient detail and type for government officials to begin the preparation of land use planning and management strategies (Sections 5.1, 5.2, and 5.3).

4.6 Biophysical (Land Management) Mapping

Selected thematic maps were used in the construction of a "Land Management" map. The ecological, regional geologic, and soils maps, in addition to the Landsat image, were used to derive a classification based on biophysical zones (Appendix D-6). The biophysical zones are units that have similar vegetation, geology, soils, and climate and, more importantly, they are units that should respond in a similar way to land management practices such as reforestation, brush or weed control, fertilization, cropping methods, etc.. The map does not represent any actual single tangible biological or physical attribute but rather a composite of attributes that define a biophysical unit. Interpretations were made to deduce suitable land management practices which could be applied based on the characteristics of the biophysical units. Thus, the name "Land Management" was assigned to the map.

The construction of this map should not be taken as a rigid or final product, but rather a technique that should be refined and extended within the Costa Rican resource management groups. The map sets no management constraints or makes any decisions. It does synthesize the data into a form that is more readily usable for land use planning and decision making.

The construction of the biophysical units and classification proceeded in a series of steps. The first step was to compile the pertinent thematic maps. The San Jose 1:200,000 topographic map sheet was used for topographic control and for defining elevation differences. Next, the soils, geology, and life zone maps were compared one at a time through the thematic overlay process. A second generation overlay was prepared showing 1000, 2000, and 3000 meter elevation contours. The soils and geology units and the life zones maps were overlayed, approximating units that had a composite of these biophysical attributes in common. Another overlay was fashioned by combining and rectifying the lines from the individual maps to each other. On this final overlay, lines were selected to define the best probable contact or unit boundary. The 1:200,000 Landsat black and white image was used as a "photographic" aid to guide the placement of unit boundaries. Each unit was labelled as it was outlined and a list was compiled of the new labels and the mapping unit conditions to which they applied. This list was rechecked to assure that there was no duplication.

The unit boundary lines and symbols were transferred to another overlay and a final copy was made for field checking. Three days were spent on the ground and a half day in a light aircraft was used to check the map units for their reasonableness as a rendition of ground conditions.

The maps were given a final revision and correction according to conditions noted in the field. It should be noted that the data base for this map is of a general nature corresponding to a 1:200,000 scale. Many of the original maps were a much smaller scale than the 1:200,000 base map and the explanations for these maps were limited. A more detailed description of the units may be achieved through further field checking and revision. However, the map is a reasonable approximation of biophysical units that would be eminently useful for land management planning and decision making within the resources sector of the GOCR. An explanation and legend for the 1:200,000 land management map can be found in Appendix D-6.

The "Land Management" map was reproduced as another overlay in the 1:200,000 thematic map series and all maps are submitted to USAID/Costa Rica and the GOCR with this final report.

5.0 NATURAL RESOURCES ANALYSIS AND MONITORING

Data acquisition and mapping were essential steps in the development of a natural resources data base, but analysis of these data is the stage that will provide significant findings to planners and decision makers. The resources data base or geographical information system, in the form of thematic maps, is the avenue that has been established for the derivation of resource information.

There were several key steps in the analysis and monitoring process. These include measurement of spatial features, superimposition and interaction of single-theme geographic phenomena, detection of land use change, and preparation for periodic monitoring. Added to these was the essential step of performing an economic analysis on the project.

For the first of these processes, area measurement of spatial features, a variety of tools were employed which ranged along a whole spectrum of degree of complexity. At the simplest, dot planimeters were used to demonstrate that such a basic tool, available to workers anywhere, would yield satisfactory results. Representing a higher level of sophistication was the use of an electronic planimeter, a machine which would probably prove to be cost-effective in any nationwide project in Costa Rica. Finally, area measurements of the mapping achieved by computer processing of satellite digital data were a simple by-product of that mapping procedure.

Another major task was the aggregation of data by useful areal units. Two basic approches to the problem were demonstrated. In the first, land cover/land use areas were aggregated for individual topographic map base units. In the second, for a test area consisting of the Canton of San Jose, land cover/land use areas were aggregated by the districts (distritos) which comprised the Canton (Appendix E). Handling the data in this way allows for the possibility of using spatial information in conjunction with ground-collected census data, presuming that they were contemporaneously acquired.

The results that are produced through various analyses performed on spatial data can only be useful if the data are reliable. Furthermore, if the data are not totally accurate, what magnitude of error can be expected? Knowing this, resource managers and planners can make the necessary adjustments in their estimates of the predicted outcome of phenomena related to these data. Landsat classification performance was evaluated to provide information of this kind. The process of interfacing single-theme spatial data; e.g., geographic phenomena of slope, land cover, drainage, was also demonstrated.

An extremely important tool in understanding the process of land conversion; e.g., forest to agricultural or agricultural to urban, developed in the course of the project. Land use change maps and estimates were made by comparing historical photographic to recent satellite images and photography. The further analysis of the type of change, its location from one historical date to another, and a measurement of the sizes of the polygons of change and their spatial pattern relative to each other provides valuable information on specifically what has happened. Perhaps more important for later projects, the nature of the process of land conversion itself can be identified. The predictive (and prescriptive) potential of this knowledge has great portent for Costa Rica.

5.1 Data Measurement and Land Cover Classification Analysis

Land cover measurements were performed for the Tarcoles and Barranca 1:50,000 base maps. These maps were selected for measurement because: 1) they represent rural areas where a variety of dispersed land uses occur, and 2) the measurement of major cover types by photo interpretation was of sufficient reliability to compare and evaluate the classification accuracy of the Landsat data which was also performed for the same areas.

The land cover meausrements provided an accurate assessment of the proportion of land encompassed by each cover class. As mentioned in Section 4.2 land use may be inferred from land cover. By knowing the true proportions of land cover classes in the map areas, resource managers can determine how much land is available for forest production, grazing, and agricultural use. More detailed analyses can follow from this preliminary assessment. For example, by combining the land cover and slope maps, area measurements of land cover on 30 degree or greater slopes revealed high-risk erosion sites and areas that may require reforestation as a soil and water conservation measure.

Landsat classification accuracy was evaluated through comparison with aerial photography on a sampling basis. Percentage of correct classification for each cover type and the associated standard error was determined. A detailed discussion of the Landsat classification performance provided insights concerning those classification errors.

5.1.1 <u>Land Cover Area Measurement</u>

Area measurements of all land cover classes were made on a cell-by-cell basis. A complete cell (20 millimeters by 20 millimeters) on the IGN 1:50,000 base map equals one square kilometer on the ground (Lambert projection). A dot grid with 25 dots per square kilometer was placed over each cell for measurement. Each dot represents the minimum mapping unit, four hectares (4 x 25 = 100 hectares per square kilometer). The land cover class under each dot was counted. The number of dots and area (in hectares) of each cover class was recorded on a tally sheet for each cell. Each cell was assigned a row and column number for identification.

The land cover area for major cover types classified from Landsat data was tabulated from a pixel count (Section 4.2.1.8) during the computer-assisted Landsat classification. Tables 5-1 and 5-2 provide the results of the area measurement of both remote sensing data sources.

5.1.2 "Protection" Forest Removed from 30 Degree or Greater Slopes

To illustrate a practical application of the thematic map process, the photo interpreted land cover maps and the slope maps were combined for analysis on the Barranca and Tarcoles 1:50,000 map sheets. The areas encompassed by all cover types occurring on 30 degree or greater slopes were measured. Area determinations are shown in Table 5-3.

A 30 degree or greater slope is considered an excessively steep incline. With the exception of rare circumstances, these slopes should not be cleared of their "protection" forest cover. The word "protection" is emphasized here because without a protective forest of dense woody cover these slopes become highly prone to erosion. The erosion hazard is increased when road building or grazing uses are imposed on the land. An example of this scenario is illustrated in Photo 2-2.

Tarcoles has nearly six times the area in 30 degree or greater slopes, however, both the Tarcoles and Barranca maps have approximately the same percentage of area in forest cover, for the 30 degree slope class (77% and 74% respectively). "Protection" forest has been removed from approximately one-quarter of the total land area on excessive slopes. Close

	Forest	Brush	Grass	Rice	Other Seasonal Agricultural	Other Perennial Agricultural	Forest Transition	Urban-Residential	Mangrove	Inland Water	Beach & Rocks	Bare Soil	Total Hectares Classified
% Landsat	21.61	14.87	49.20	*	*	*	*	*	3.26	*	*	11.06	
Hectares	5176	3562	11784	-	-	-	-	-	781	-	-	2649	23952
% Photo Inter-prepation	35.66	6.73	52.02	.61	.02	.12	.09	.29	3.14	.58	.74	*	
Hectares	11052	2086	16124	186	6	38	28	88	972	180	228		30990
% Difference	-14.05	+8.14	-2.82						-.12				

* Not classified

Table 5-1: LANDSAT AND PHOTO INTERPRETATION LAND AREA CLASSIFIED FOR ALL COVER CLASSES: TARCOLES 1:50,000 MAP SHEET

	Forest	Brush	Grass	Rice	Cane	Other Seasonal Agriculture	Other Perennial Agriculture	Urban-Residential	Agriculture and Urban Transition	Mangrove	Marsh	Inland Water	Beach Docks Rocks	Bare Soil	Total Hectares Classified
% Landsat	1.42	8.60	76.89	*	1.99	*	*	.27	*	1.41	*	*	*	9.42	
Hectares	625	3782	33817	-	875	-	-	119	-	620	-	-	-	4143	43981
% Photo Inter-preparation	12.53	8.12	67.79	1.32	1.49	1.90	1.68	.90	.33	2.07	.17	1.40	.29	*	
Hectares	5640	3654	30508	594	672	858	754	404	150	930	76	632	132	-	45004
% Difference	-11.11	+.48	+9.1		+.05			-.63		-.66					

* Not classified

Table 5-2: LANDSAT AND PHOTO INTERPRETATION LAND AREA CLASSIFIED FOR ALL COVER CLASSES: BARRANCA 1:50,000 MAP SHEET

Barranca 1:50,000 Map Sheet - Slopes Greater Than 30 Degrees

	Cover	Area	Percentage
41	Forest	110 hectares	74%
39,35	Brush	32 hectares	20%
31,32	Grass	10 hectares	6%
Total		160 hectares	100%

0.52% of total map area

Tarcoles 1:50,000 Map Sheet - Slopes Greater Than 30 Degrees

	Cover	Area	Percentage
41	Forest	704 hectares	77%
34,35	Brush	92 hectares	10%
31,32	Grass	117 hectares	13%
Total		913 hectares	100%

3% of total map area

Table 5-3: SLOPE VS. LAND COVER COMPARISONS FOR BARRANCA AND TARCOLES 1:50,000 MAP SHEETS inspection of aerial photographs or ground visitation of those sites may reveal active gully erosion which is a major contributor to river or reservoir siltation and reduction of water quality. Reforestation of these areas may be necessary to retard erosion and increase water quality.

Looking at this data from another perspective, a prime area for reforestation, which could be delimited through analysis of the thematic maps, would be a watershed for a municipal water supply. The maps useful to derive this information would be: 1) watersheds, 2) slope, and 3) nonforest land cover.

5.1.3 Evaluation of Landsat Land Cover Classification

Landsat land cover classification accuracy was evaluated through comparison of Landsat land cover sample points to the same points where photo interpretation was performed. The photo interpreted land cover served as the surrogate of actual ground conditions.

It should be noted that the percentage of correctly classified sample points on the Landsat land cover maps cannot be expected to attain 100% when compared to a map derived by photo interpretation. The photo interpreted land cover maps have their own inherent accuracy which is not 100%.

The major land cover types classified from Landsat data: forest, brush, grass, urban, and mangrove) are so general that their frequency of being misidentified by the photo interpreter is assumed to be low. Accordingly, the verification of Landsat classification accuracy by photo interpretation should have validity.

There are certain limitations and assumptions that affect the stated Landsat classification accuracy.

The most current and cloud-free (30% cloud cover) Landsat scene available was imaged on March 3, 1975. 1978 aerial photography was required for the land cover mapping project to obtain full and current coverage of the study area. The three year difference in the data sources incorporates an undetermined amount of error to the verification approach due to land cover/land use changes which occurred during the three year interval.

Multiseasonal Landsat data were not available to aid the Landsat classification of seasonal cropping patterns and to provide additional data for the land area that was obscured by clouds in the 1975 Landsat scene. This limitation is not uncommon for tropical countries.

The land cover maps are comparable to the four hectare minimum mapping unit assuming that the registration of both data sources to their true ground location are exact. The registration of both data sources to the base maps was undertaken with great care using the best available techniques.

Some location-specific and linear information was lost as a result of the aggregation and resampling of Landsat pixel data to the 1:50,000 base map scale. The undersampling of the Landsat data did not appear to introduce any noticeable effects.

5.1.3.1 Sampling Method

After the land cover area measurements were recorded for the Tarcoles and Barranca map sheets, the proportion of the total map land area encompassed by each land cover class was determined. Sample units (cells) were proportionally allocated to each land cover strata. Sample size was arbitrarily chosen to be approximately 5% of the total land area on the map.

The sample design is that of a stratified cluster sample. The modification from a standard stratified cluster sample is that the strata are artifically assigned to a cell and the cells are selected by unequal or variable probability instead of equal probability. Each cell contains a cluster of measurements. The cluster size varies with the proportion of the cell area in the primary cover class (e.g., grass in the grass stratum). The probability of selecting any cell in the sample is the number of primary cover class hectares (P_i) divided by the total number of hectares of the cover class (N_g) for the entire map population; thus, P_i/N_i = probability of selection. The cells with greater proportional area in the cover class of interest had higher probability of being selected. For example, if a cell in the grass stratum must be sampled, a random number table is used to select a number equal to or less than the total hectares of grass in the population (N_g). The number selected represents the cumulative number of hectares of primary cover class (grass) which correspond to a particular cell (on the tally sheets) identified by a row-column number. The IGN base map and both the Landsat and photo interpreted land cover maps were registered in overlay fashion. The dot grid was placed over the sample cell and each dot within the cover class stratum was recorded for direct point (four hectares) comparison of both data sources. This procesure was duplicated for all sample cells. The sample comparisons are displayed in a two-dimensional matrix (Tables 5-4 and 5-5).

5.1.3.2 Landsat Classification Accuracy

Tables 5-4 and 5-5 display the number of sample points classified from each remote sensing data source. The entry in each box shows the number of points for each cover class classified by Landsat (horizontal axis) and by photo interpretation (vertical axis) methods. The boxes corresponding to the same cover class on each axis represent the "degree of association" or the number of points that were correctly identified by Landsat as verified by the photo interpretation "truth". All other boxes represent the number of points that were

P.I. Sample Points \ Landsat Sample Points	Forest	Brush	Grass	Urban	Mangrove	Bare Soil	(No Data) Clouds Shadow	Photo Total Points	Photo % Total Sample
Forest	61	20	19			7	31	138	36.37
Brush	2	5	10			2	8	27	7.11
Grass	4	19	100			18	55	196	51.58
Rice			2			2		4	1.05
Seasonal Agriculture									
Perennial Agriculture									
Urban-Residential		1	1					2	.53
Mangrove			1		9	1		11	2.90
Inland Water							1	1	.26
Beach, Dock, Rock						1		1	.26
Landsat Total Points	67	45	133		9	31	95	380	
% Landsat Total Sample	17.63	11.84	35.00		2.37	8.16	25.00		

Table 5-4: LANDSAT VS. PHOTO INTERPRETATION POINT SAMPLE COMPARISON: TARCOLES 1:50,000 BASE MAP

P.I. Sample Points \ Landsat Sample Points	Forest	Brush	Grass	Urban	Mangrove	Bare Soil	(No Data) Clouds Shadow	Photo Total Points	Photo % Total Sample
Forest	8	26	28			18		80	14.47
Brush		8	41			8		57	10.31
Grass		16	283			28		331	59.86
Rice			14			4		18	3.26
Seasonal Agriculture			12			2		14	2.53
Sugar Cane			8					8	1.45
Perennial Agriculture			6					6	1.09
Urban-Residential			1	2		1		4	.72
Mangrove		3			13			16	2.89
Inland Water		1	1			15	2	19	3.44
Beach, Rock									
Landsat Total Points	8	54	394	2	13	76	6	553	
Landsat % Total Sample	1.45	9.77	71.25	.36	2.35	13.74	1.09		

Table 5-5: LANDSAT VS. PHOTO INTERPRETATION POINT SAMPLE COMPARISON: BARRANCA 1:50,000 BASE MAP

misclassified by Landsat or confused with other land cover classes.

By comparing the cover class proportions in the sample (last row and column of Tables 5-4 and 5-5, to the actual proportions classified by both data sources (Tables 5-1 and 5-2), the reader can get some indication of how representative the sample was of the actual (complete enumeration) land cover class proportional distributions.

Two methods were used to compare the remote sensing data sources. The first method is to view the matrix from the "column" perspective, where the Landsat sample distribution is displayed for each cover type. Tables 5-6 and 5-7 provide the percentage of the total Landsat sample points that were correctly classified, the residual percentages associated with photo verified cover classes that were not correctly classified from Landsat data, and the correct classification percentage and associated standard error for each cover class and all cover classes combined. The 95% confidence limits were determined from the formula (17):

$$P \pm \{t_{.05} \sqrt{\frac{P(100-P)}{n}} + 50/n\}$$

where P is the approximate value of the true portion correctly expressed as percentage, and n is the number of points sampled. The second method of comparison is to view the matrix (Tables 5-4 and 5-5) from the "row" perspective, where the photo interpretation sample distribution is displayed for each cover type. Tables 5-8 and 5-9 summarize the results of the row perspective for the Tarcoles and Barranca maps respectively. Tables 5-8 and 5-9 provide the percentage of the total photo sample points that were correctly classified from Landsat data, the residual percentages associated with photo verified cover classes that were not correctly classified from Landsat data, and the correct classification percentage with associated standard

	% of Total Landsat Points Correctly Classified	% of Cover Classes Misclassified	% Correct ± 95% Confidence Limit
Forest	8/8 x 100 = 100.00		= 100 ± 0
Brush	8/54 x 100 = 14.82	Forest = 48.15 Mangrove = 5.56 Grass = 29.63	$14.82 \pm \{2.003\sqrt{\frac{14.8(85.2)}{57}} + 50/57\} = 14.8 \pm 10.3$
Grass	283/394 x 100 = 71.83	Forest = 7.11 Brush = 10.41	$71.8 \pm \{1.96\sqrt{\frac{71.8(28.2)}{394}} + 50/394\} = 71.8 \pm 2.4$
Urban	2/2 x 100 = 100.00		Insufficient sample data.
Mangrove	13/13 x 100 = 100.00		= 100 ± 0
Total % Correct For All Cover Classes	314/471 x 100 = 66.7		$66.7 \pm \{1.96\sqrt{\frac{66.7(33.3)}{471}} + 50/471\} = 66.7 \pm 4.4$

Table 5-7: LANDSAT CLASSIFICATION ACCURACY FOR MAJOR LAND COVER CLASSES BASED ON LANDSAT SAMPLE POINTS: BARRANCA 1:50,000 BASE MAP

	% of Total Landsat Points Correctly Classified	% of Cover Classes Misclassified	% Correct ± 95% Confidence Limit
Forest	61/67 x 100 = 91.05	Brush = 2.99 Grass = 5.97	$91.1 \pm \{1.998\sqrt{\frac{91.1(8.9)}{67}} + 50/67\} = 91.1 \pm 7.7$
Brush	5/45 x 100 = 11.11	Forest = 44.44 Urban = 2.22 Grass = 42.22	$11.1 \pm \{2.016\sqrt{\frac{11.9(88.1)}{45}} + 50/45\} = 11.1 \pm 10.6$
Grass	100/133 x 100 = 75.19	Forest = 14.29 Mangrove = .75 Brush = 7.52 Urban = .75	$75.2 \pm \{1.96\sqrt{\frac{75.2(24.8)}{133}} + 50/133\} = 75.2 \pm 7.7$
Urban	----------------No Data----------------		
Mangrove	9/9 x 100 =100.00		$=100.0 \pm 0$
Total % Correct For Major Cover Classes	173/254 x 100 = 68.1		$68.1 \pm \{1.96\sqrt{\frac{68.1(31.4)}{254}} + 50/254\} = 68.1 \pm 5.9$

Table 5-6: LANDSAT CLASSIFICATION ACCURACY FOR MAJOR LAND COVER CLASSES BASED ON LANDSAT SAMPLE POINTS: TARCOLES 1:50,000 BASE MAP

	% of Total Photo Sample Points Correctly Classified by Landsat	% of Cover Classes Misclassified	% Correct ± 95% Confidence Limit
Forest	61/107 x 100 = 57.01	Brush = 18.69 Bare Soil = 6.54 Grass = 17.76	$57.0 \pm \{1.984\sqrt{\frac{57(43)}{107}} + 50/107\} = 57.0 \pm 10$
Brush	5/19 x 100 = 26.32	Forest = 10.53 Grass = 52.63 Bare Soil = 10.53	$26.3 \pm \{2.093\sqrt{\frac{26.3(73.7)}{19}} + 50/19\} = 26.3 \pm 23.8$
Grass	100/141 x 100 = 70.92	Forest = 2.84 Brush = 13.48 Bare Soil = 12.77	$70.9 \pm \{1.96\sqrt{\frac{70.9(29.1)}{141}} + 50/141\} = 70.9 \pm 7.9$
Urban	---------------No Data-----------------		
Mangrove	9/11 x 100 = 81.92	Grass = 9.09 Bare Soil = 9.09	$81.8 \pm \{2.201\sqrt{\frac{81.8(18.2)}{11}} + 50/11\} = 81.8 \pm 30.2$
Total % Correct For Major Cover Classes	173/278 x 100 = 62.2		$62.2 \pm \{1.96\sqrt{\frac{62.2(37.8)}{278}} + 50/278\} = 62.2 \pm 5.9$

Table 5-8: LANDSAT CLASSIFICATION ACCURACY FOR MAJOR LAND COVER CLASSES BASED ON PHOTO SAMPLE POINTS: TARCOLES 1:50,000 BASE MAP

	% of Total Photo Sample Points Correctly Classified by Landsat	% of Cover Classes Misclassified	Correct ± 95% Confidence Limit	
Forest	8/80 x 100 = 10.0	Brush = 32.5 Grass = 35.0 Bare Soil = 22.5	$10 \pm \{1.993\sqrt{\frac{10(90)}{80}} + 50/80\}$	= 10.0 ± 7.3
Brush	8/57 x 100 = 14.04	Grass = 71.93 Bare Soil = 14.04	$14 \pm \{2.009\sqrt{\frac{14(86)}{57}} + 50/57\}$	= 14 ± 10
Grass	283/327 x 100 = 86.54	Brush = 4.89 Bare Soil = 8.56	$86.5 \pm \{1.96\sqrt{\frac{86.5(13.5)}{327}} + 50/327\}$	= 86.5 ± 3.9
Urban	2/4 x 100 = 50.00	Grass = 25.0 Bare Soil = 25.0	Insuffient data	
Mangrove	13/16 x 100 = 81.25	Brush = 18.75	$81.3 \pm \{2.120\sqrt{\frac{81.3(18.7)}{16}} + 50/16\}$	= 81.3 ± 23.8
Total % Correct For All Cover Classes	314/484 x 100 = 64.9		$64.9 \pm \{1.96\sqrt{\frac{64.9(35.1)}{484}} + 50/484\}$	= 64.9 ± 4.4

Table 5-9: LANDSAT CLASSIFICATION ACCURACY FOR MAJOR LAND COVER CLASSES BASED ON PHOTO SAMPLE POINTS: BARRANCA 1:50,000 BASE MAP

error. Tables 5-8 and 5-9 calculations exclude the sample points where no data were obtained, those where clouds, shadows, and water were sensed by the Landsat scanner. The row perspective provides a more meaningful evaluation of Landsat classification accuracy because the percentages are based on the "photo truth" sample points. For example, Table 5-6 shows that out of 67 forest sample points classified from Landsat data, 61 were verified as forest by photo interpretation. Thus, we infer that Landsat was 91% correct when a pixel was classified as forest. These results require further explanation, however, since Table 5-8 shows that out of 107 photo interpreted forest sample points, only 61 were correctly identified as forest from Landsat data, yielding only 57% Landsat classification accuracy.

The residual percentages of cover classes not correctly classified provide further information to be scrutinized. For example, the Landsat brush classification for Barranca was only 15% correct (Table 5-7) and 14% correct (Table 5-9); however, 48% and 30% of the Landsat brush was photo verified as forest and grass respectively in Table 5-7. In Table 5-9, 72% of the photo interpreted brush was classified as grass by Landsat, and none of the photo interpreted brush was classified as forest from Landsat data. Possible explanations of these results can be provided with some understanding of the Landsat classification procedures and knowledge of the study area. It appears that the Landsat forest category is relatively "tight", that is, only a narrow range of reflectance values are accepted by the classifier, because the forest training sites were selected from dense virgin forest. A pixel composed of less dense forest or "cutover" forest (with a brush and/or grass component) may yield a reflectance value that is not within the forest class spectral reflectance range causing the pixel to be classified as something else (e.g., brush or grass). The same site may be classified as forest by the photo interpreter. In contrast, the Landsat grass category accepts a broad range of reflectance values because some of the grass training sites were selected in areas that were dominantly grass and others were selected in areas that had a substantial brush component. Through further examination it became apparent that the Landsat classifier could not distinguish subtle differences in brush and grass proportions and all of the grass classes were grouped into one grass category for the final classification (Section 4.2). In view of this, the areas that the photo interpreter classifies as brush (greater than 60% brush) could possibly contain as much as 39% grass and many of these areas were classified as grass from Landsat data. There were originally 17 Landsat grass classes, eight Landsat forest classes, and only one Landsat brush class. The Landsat brush class was originally thought to represent a combination of brush and trees. However, there is some indication that the Landsat brush category may be a combination of average reflectance values such as forest and bare soil. In the Barranca study area, most of the remaining forest is confined to stream courses. These forest corridors are often less than 80 meters wide, contain some open water and fluvial deposits, and are often bordered by grazing land (grass and brush). A Landsat pixel (80 meter resolution) that is located along the forest boundary may return a mixed signal that resembles the brush reflectance value. On the other hand, if there is a large proportion of grass, the pixel may be classified as grass. This may partially explain why the Landsat forest classification appears to be poor for the Barranca base map as verified by the photo interpreted forest.

Tables 5-6 through 5-9 compare only the major cover classes classified from both remote sensing data sources. Some of the photo interpreted land cover classes (e.g., rice and other seasonal agriculture) were not included in the Landsat classification. These classes were not included because the Landsat images are from March 3rd when there was practically no mature rice or vegetables in the field. The lowland rice fields were fallow and the dry land rice fields were often exhibiting remnants of the previous crop (e.g., corn stubble) or herbaceous plants that invade as the land lies dormant between crop cycles. The fallow fields are often classified as bare soil from Landsat data. The herbaceous condition of the dry land fields makes seasonal agriculture virtually indistinguishable from grass dominant pastureland to the Landsat scanner and also taxes the photo interpreter's ability to identify a crop pattern. However, in the case of photo interpretation, the fields usually exhibit a distinctive square or rectangular pattern in addition to a sparsely vegetated condition which helps the interpreter to distinguish seasonal agriculture from common pasture or grass land. Rice can often be identified by small white dots on the air photos indicating where the rice was stacked in piles before being removed from the fields. Many of the dry land fields are below the ground resolution capabilities (80 meters) to be detected by Landsat and they are often smaller than the minimum mapping unit (25 mm). It is a safe assumption to say that the total land area encompassed by rice and seasonal agriculture was underestimated by photo interpretation (Tables 5-1 and 5-2) as some of the dry land fields were not identified and many were smaller than the MMU. The Tempisque Valley study (Baumgardner, et. al., 1976) reported that Landsat classification as compared to an agricultural census underestimated the area of rangeland and forest. Tables 5-1 and 5-2 in this report also show Landsat underestimates for grass with a brush component (comparable to the Tempisque rangeland category) and forest.

The heterogeneous vegetation patterns resulting from massive land conversion (forest cutting, shifting agriculture, etc.) within the Tarcoles and Barranca map areas, represent one of the most difficult mapping conditions of any example that could have been chosen to test the Landsat classification accuracy in Costa Rica. Also, it should be noted that the Landsat vs. photo interpretation sample is based on point comparisons which is generally a more rigorous test of accuracy than an area (non-point) comparison test like the one used in Table 12 of the Tempisque Valley report (18). For example, Table 5-9 in this report shows an extremely poor Landsat point classification accuracy for brush (14% correct) but the area comparison of Landsat vs. photo interpreted brush is nearly identical (Table 5-2 in this report).

If the rigorous USGS classification accuracy standard of 85% correct plus or minus 5% standard error at the 95% probability level is applied to the combined classification results of the Tarcoles and Barranca study areas (Table 5-10), only the Landsat Grass (82%) and Mangrove (82%) classifications approach acceptable standards based on photo sample points. In a similar test based on Landsat sample points, only the Forest class (92%) meet these standards. This is primarily a function of the "tight" descriptive classifications developed for Forest, Brush and Grass classes.

In summary, where Landsat data indicate "forest", these data are correct 91% of the time, at the 95% confidence level. Small, irregularly shaped and less dense areas of tree cover, typically along the edges of streams, may be identified as "forest" in photo interpretation but classified as "brush" by Landsat. Where these conditions occur frequently, as in the Tarcoles and Barranca areas, Landsat estimation of forest area may differ significantly from the photo estimate.

The number of sample points necessary to bring the mangrove standard error down to plus or minus 5% can be determined by the formula

$$n = \frac{pxq}{d^2} = \frac{81.5 \times 18.5}{52} = 60$$

where P is the desired proportion, q is 100 - P, d is the acceptable standard error, and n is the number of samples. P, q, and d are expressed as percentages. As 27 points were taken in the mangove sample, 33 additional points would be required (27 + 33 = 60) to obtain 81.5% accuracy with plus or minus 5% standard error.

Tables 5-1 and 5-2 display the actual percentage of the total land area classified by both data sources based on the pixel count from the Landsat computer printout and the dot grid measurements for the photo interpretation classes. The bottom line shows the percentage difference in the classification

Forest	$92 \pm \{1.995\sqrt{\frac{92(8)}{75}} + 50/75\} = 92 \pm 6.9$	$36.9 \pm \{1.96\sqrt{\frac{36.9(73.1)}{187}} + 50/187\} = 36.9 \pm 7.7$
Brush	$13.1 \pm \{1.987\sqrt{\frac{13.1(86.9)}{99}} + 50/99\} = 13.1 \pm 7.2$	$17.1 \pm \{1.994\sqrt{\frac{17.1(82.9)}{76}} + 50/76\} = 17.1 \pm 9.3$
Grass	$72.7 \pm \{1.96\sqrt{\frac{72.5(27.5)}{531}} + 50/531\} = 72.7 \pm 3.9$	$81.8 \pm \{1.96\sqrt{\frac{81.8(18.2)}{468}} + 50/468\} = 81.8 \pm 3.6$
Urban	Insufficient Sample Data	Insufficient Sample Data
Mangrove	$= 100 \pm 0$	$81.5 \pm \{2.052\sqrt{\frac{81.5(18.5)}{27}} + 50/27\} = 81.5 \pm 17.2$
Total % Correct For All Cover Classes	$67.5 \pm \{1.96\sqrt{\frac{67.5(37.5)}{725}} + 50/725\} = 67.5 \pm 3.5$	$64.2 \pm \{1.96\sqrt{\frac{64.2(35.8)}{762}} + 50/762\} = 64.2 \pm 3.5$
	(Based on Landsat Sample Points)	(Based on Photo Sample Points)

Table 5-10: LANDSAT % CORRECT CLASSIFICATION ± 95% CONFIDENCE LIMITS OF MAJOR COVER CLASSES. TARCOLES AND BARRANCA 1:50,000 BASE MAP

proportions as a minus for the area of cover types underestimated and a plus for the area of cover types over-estimated by Landsat. True urban areas are non-existent on the Tárcoles map and residential areas (low density housing) were excluded from the Landsat classification because the proportion of the total land area in this class was insignificant. In many cases, trees or grass dominate the Landsat pixel in residential areas and classification errors would occur as the Landsat sensor distinguishes reflectance values of cover classes and not land use. Other photo interpreted cover classes that do not appear in the Landsat classification for these map populations were excluded for the same reason.

There were no Landsat data (clouds, shadows, inland waters) available for 7038 and 1023 hectares of land area for the Tarcoles and Barranca sheets respectively. There were 180 hectares and 632 hectares of inland water estimated from photo interpretation for the Tarcoles and Barranca maps respectively. By subtracting the inland water category from the no-data class on both maps, cloud and shadow classes represent an estimated 6858 hectares on the Tarcoles map and 340 hectares on the Barranca map. The percentages and number of hectares associated with each cover class are based on the total cloud-free area classified by either remote sensing data source. The absence of Landsat land cover data for a substantial portion of the land area (primarily in forest and grass cover) on the Tarcoles map, creates great difficulty in comparing the differences in the Landsat vs. photo interpreted cover class percentages classified on the Tarcoles map to the Barranca map. If there were complete land cover data available for both maps, we would assume that the classification results should show similar trends or a similar magnitude of over-estimates and under-estimates for each cover type. This assumption should be valid because the Landsat computer classifier uses the same decision criteria to assign a pixel to any land cover class and the photo interpreter uses the same mapping guidelines from one area to another.

5.2 Multistage Sample Design for Naranjo Coffee Area Estimation

To illustrate another application of thematic map data (land cover) for resources analysis and monitoring, a multistage sample design for coffee area estimation was conducted. A sample selection procedure similar to the one discussed in Section 5.1.3 was applied to the Naranjo coffee study area, except that here the number of hectares in coffee production was the only cover type of interest. The probability of selecting any sample unit (Primary Sampling Unit - PSU) was based on a preliminary Landsat coffee estimate, and then correlated with 1:40,000 CIR photo interpreted coffee area measurements. The selection probabilities were entered directly into the equations to determine the variance, standard deviation and sample error associated with the coffee area estimate. This type of sample design is called "multistage" which commonly uses two more more types (or scales) of remote sensing data (usually Landsat at the first stage and small, medium, or large scale photography at the later stages). Ideally, the estimates should be compared against ground data, but like the Barranca and Tarcoles map areas, no ground sampling data were available. Previous investigations (19) have shown that when several scales of remote sensing imagery are available, it is often most efficient to first make a large number of fast, inexpensive measurements of a parameter (xi), on small scale, low resolution imagery and then compare this with the parameter of interest (yi).

The Naranjo study area is outlined in Figure 5-1. The Landsat data for the Naranjo coffee region was geographically stratified (Section 4.2.1.5) so that coffee would not be confused with forest which reflects similarly to coffee (especially shaded coffee), but rarely occurs in the study area. Only a portion of the total Naranjo coffee region was sampled because complete photo coverage was not available and part of the area was obscured by clouds.

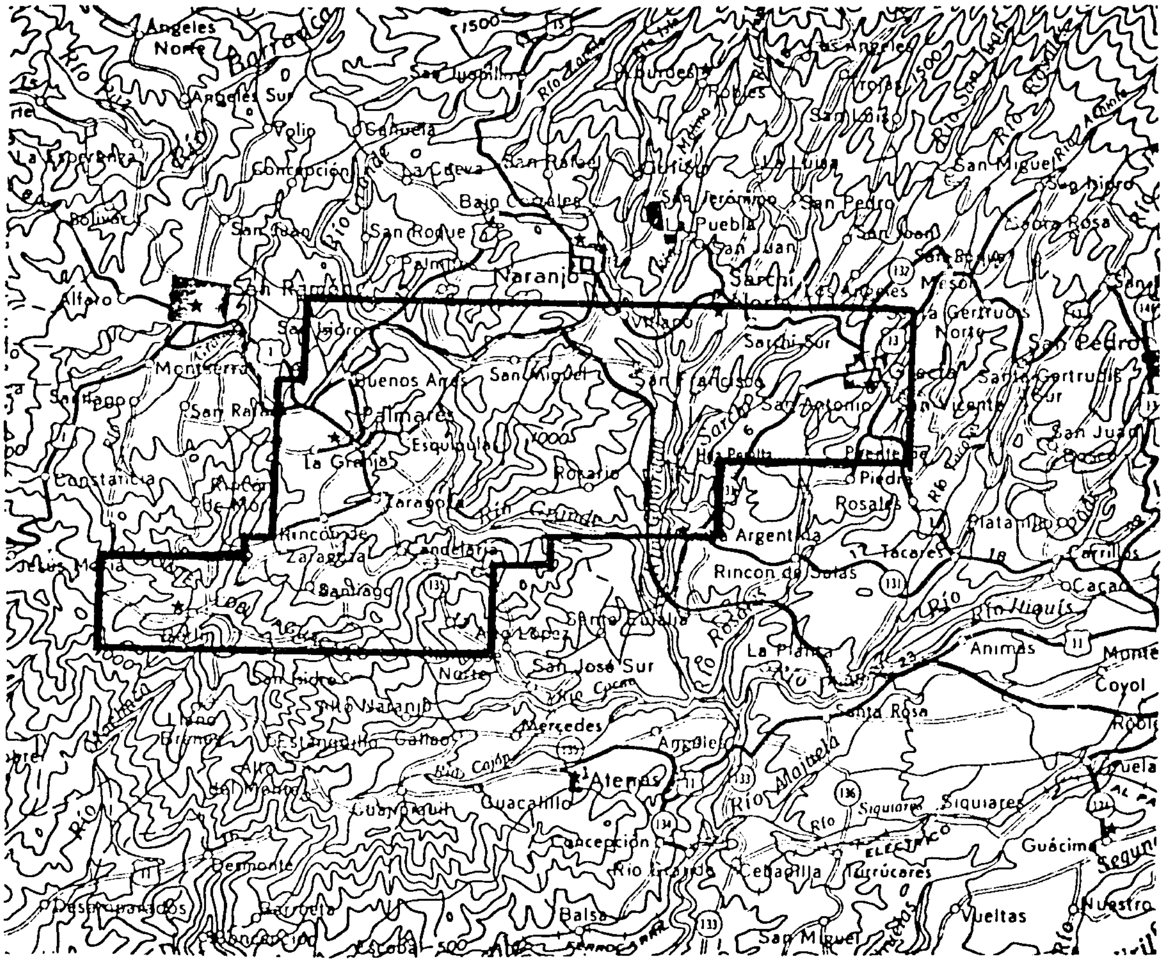


Figure 5-1: NARANJO COFFEE STUDY AREA

The sample data and results are displayed in Table 5-11. The estimated hectares of coffee (H) in the Naranjo study area was 6221 plus or minus 491 hectares at one standard deviation (7.9% sample error). The total area of coffee in the study area, measured with a dot grid from the photo interpreted land cover maps, was 6372 hectares. This estimation technique shows promise for the inventory and monitoring of coffee production in Costa Rica. Not only was the estimate of reasonable accuracy, but the sampling method is fast and inexpensive. A multistage sampling approach with stratification of coffee and urban lands at the first stage may be a useful tool for monitoring urban expansion into prime coffee land.

5.3 Land Cover/Land Use Change Detection

One of the original intentions of the Pilot Project was to use 1975 and 1978 Landsat imagery to detect and measure land use changes which had occurred between the two dates. It was planned that each data set would be processed by computer and the results compared. However, the only available scene for 1978 with minimal cloud cover could not be converted by NASA to a computer compatible tape format. Therefore, a digital change detection could not be accomplished.

Measuring change through visual interpretation of Landsat and aerial photography was adopted as a substitute. Fortunately, a historical record of the landscape was available for much of Costa Rica in the form of black and white aerial photography. Especially useful were pictures taken in 1945 and 1965. The former represented the countryside at the close of World War II, prior to commencement of the rapid development which has since taken place in Costa Rica. The 1965 imagery freezes time at a moment near the middle of this modern "development". Using information from both of these dates and comparing it with data from the present enabled analysts to trace the major sequences of changes which have been important in shaping Costa Rica as it appears today.

Primary Sampling Unit (PSU)	Landsat Predicted Hectares	Probability of Selection (Pi)*	Photo Interpretation Measured Hectares (hi)
0806	88	.01542236	92
0421	48	.00841220	24
0417	76	.0133193	92
0307	56	.00981431	56
0314	76	.0133193	80
0908	80	.01402033	76
0316	76	.0133193	92
1010	48	.00841220	72
0907	76	.0133193	64
0710	40	.0070102	60
1108	44	.0077112	52

$$H = \frac{1}{n}\sum_{i=1}^{11} hi/pi = 6221$$

$$Var(H) = \frac{1}{n(n-1)}\left\{\sum_{i=1}^{11}\frac{hi^2}{Pi^2} - nH^2\right\} = 1/11(10)\,[452238448 - 425725788] = 241024$$

Standard deviation = 491

Sample error = 7.9%

95% C.I. = 491(2.228) = 1094; 17.6% sample error @ .95 C.I.

r^2 = .73

* Pi = probability of selecting the sample unit. The divisor is the cummulative total predicted Landsat hectares in the study area; 5706; e.g., PSU 0806; Pi = 88/5706 = .01542236.

Table 5-11: NARANJO COFFEE AREA ESTIMATION RESULTS

A variety of techniques were applied to show the many options opened to an analyst for determining land use change. The first technique includes complete measurements of rates, trends, and location of important agricultural-urban land conversion around the Costa Rican capital, San Jose, and surrounding satellite cities in the Meseta Central. Different types of land use changes were measured over two time periods: 1945 to 1965; and 1965 to 1978. Maps, photos, and tables provide an accurate assessment of these phenomena. An urban growth projection model was applied to these data to predict future trends and rates of land use change.

The second technique of determining change was applied to a much larger area. The Barranca 1:50,000 map sheet was selected to estimate all types of land cover/land use changes occurring from 1944 to 1978.

Land cover/land use change is one of the most important sources of information available to planners. Planners can begin to cope with problems of paramount importance to Costa Rica by learning rates, trends, and location of forest, agricultural, and urban land conversion. These data provide a basis for needed conservation and land use planning policies. Continual monitoring of change through remote sensing techniques can ensure compliance with newly developed regulations and provide a steady flow of information to keep government officials abreast of new developments.

5.3.1 Urbanization of the San Jose Metropolitan Area

In Costa Rica, as in most of Latin America, one city is far more important to the life and economy of the country than are any of the rest of the country's cities. The City of San Jose and its urban environs form a metropolitan region containing a majority of the country's total population and a major share of Costa Rica's economy is concentrated in this area as are centers of government and culture. As with other Latin American countries, there has been a tendency in recent decades for the metropolitan area to grow rapidly, both in population and area, at the expense of the agricultural sector. Employment opportunities have concentrated in the metropolitan area as the economy of the country has been shifting from reliance on the production of basic export agricultural commodities to processing, manufacturing, and the provision of sophisticated services.

The process of urbanization of the metropolitan area, following similar patterns recognized in the United States (and elsewhere), consists of several distinctive components. First, the central city of the metropolitan area grows both upward (with the replacement of older, lower buildings with new highrise structures) and outward by accretion. Commonly in this process, peripheral expansion goes beyond the existing corporate boundaries of the city. Because statistics are ordinarily reported for corporate units and are difficult to aggregate for unincorporated areas at the city edge, there is often confusion over the amount of urbanization which has taken place. Particularly difficult is an accounting of the discontiguous exclaves of urban development which lie beyond the contiguously built-up central city.

Several discrete sub-types of urban exclaves were identified. First, there were outlying satellite towns, each with a well-developed center. These grow outward beyond their original boundaries to meet urban expansion coming outward from the central city. Second, urban development tracts fully urban in character were plotted in the intervening rural area. These were planned units complete with streets plus other improvements, with designed building and population densities (if residential) equal to those existing in the central city. There were also planned, industrial-commercial units which displayed new, modern, international design. The third type of exclave was the low-density type of linear development which often occurred along roads and highways. These units were unplanned and evolved as land was subdivided along road frontages.

As the process of urbanization proceeded, all of these discrete units began to coalesce. Identities were lost; satellite towns, as they were engulfed and became part of the urban mass, lost their distinctiveness as individual towns and eventually became only neighborhoods within the larger city. Housing developments (such as some of those built by INVU) formerly surrounded by agricultural land had also become engulfed by urban developments and appear now only as neighborhoods within the larger mass.

As these political distinctions became more difficult to make, an accompanying difficulty was encountered in measuring area and population. Judgments vary on which areas are to be included in calculating total area and population of urbanized areas. A strong tendency remains to use recognized political units, such a towns, as the building blocks of the urbanized areas.

A formalized method to determine the composition of contiguously built-up areas used in the United States is expressed in Census Bureau rules to delimit urbanized areas. In this method, an urbanized area is composed of a central city plus all the contiguous or nearly contiguous urban exclaves which surround it.

The measurement, monitoring, and analysis of this growth of the metropolitan area is a concern of planning officials in Costa Rica and is documented in Hipotesis de Desarrollo Urbano para la Poblacion del Valle Central (1976) and OPAM (Oficina de Planamiento del Area Metropolitana) (1975) both produced by the Departmento de Urbanismo of the Instituto Nacional de Vivienda y Urbanismo. These documents reveal that between 1945 and 1973, total built-up land in the metropolitan area increased 3.7 times (from 1,066 to 3,963 hectares) and population increased 3.5 times (from 141,000 to 487,842 persons). Measurements of the central city and the exclaves from the photo interpreted maps revealed that the metropolitan area (presuming the same data base) had increased farther in area from 1973 to 1978. The total area of city and exclaves combined in 1978 was 5351 hectares compared to the published figure of 3963 hectares in 1973, or an increase in built-up area of 35%, nearly 14 square kilometers, in just five years.

5.3.2 Agricultural/Urban Land Use Change in the Meseta Central

The pattern of agricultural to urban land use change in Costa Rica is similar to that occurring throughout both the "developed" and "developing" world. Examining the pattern in the economically important Meseta Central from the City of San Jose outward, the area is seen to be composed of distinctive units. In the center lies the contiguously built-up mass comprising the original plotted center of the central city, with its narrow (approximately 10 meters wide) streets and square blocks of one mansana (100 varas or approximately 80 meters on a side) and additions in the periphery which have been added in the last fifty years or so. The area of contiguous San Jose in 1978 is 1,379 hectares and forms 8.3% of the total urban-affected land in the Meseta Central (see Table 5-12 and Figure 5-2).

A narrow band of non-built-upon land surrounds this contiguous center and its urban exclaves. As with similar cities elsewhere, the exclaves fall into three distinctive types. First, there are the satellite towns (Figure 5-2). All were once distinctive communities separated from the city by extensive rural, mostly agricultural, land. For example, Heredia and Santo Domingo, lying close to the periphery of the metropolitan area, remain fairly distinctive. The separation between other towns and the urban mass is blurred. Examples are the former satellites of San Juan de Tibas, Guadalupe, San Pedro, Curridabat, Desamparados, Escazu, and Pavas. Not only are they nearly connected physically with contiguous San Jose but they have themselves expanded outward in all directions from their original plotted areas.

1978

Types of Area	Number	Average Area (ha)	Total Area (ha)	Percent of Total
Contiguously Built-Up San Jose	1	-	1,379	8.3
Exclaves				
Satellite Towns	7	72	501	3.1
Concentrated Urban	48	57	2,752	16.6
Sparse Settlements	51	14	719	4.3
Exclaves total	106	37	3,972	23.9
Vacant Land Among Exclaves Lying Between Contiguous San Jose and Line Connecting Exclaves	1	-	11,213	67.7
Totals	108	-	16,564	

Table 5-12: SAN JOSE, URBAN EXCLAVES AND VACANT LANDS

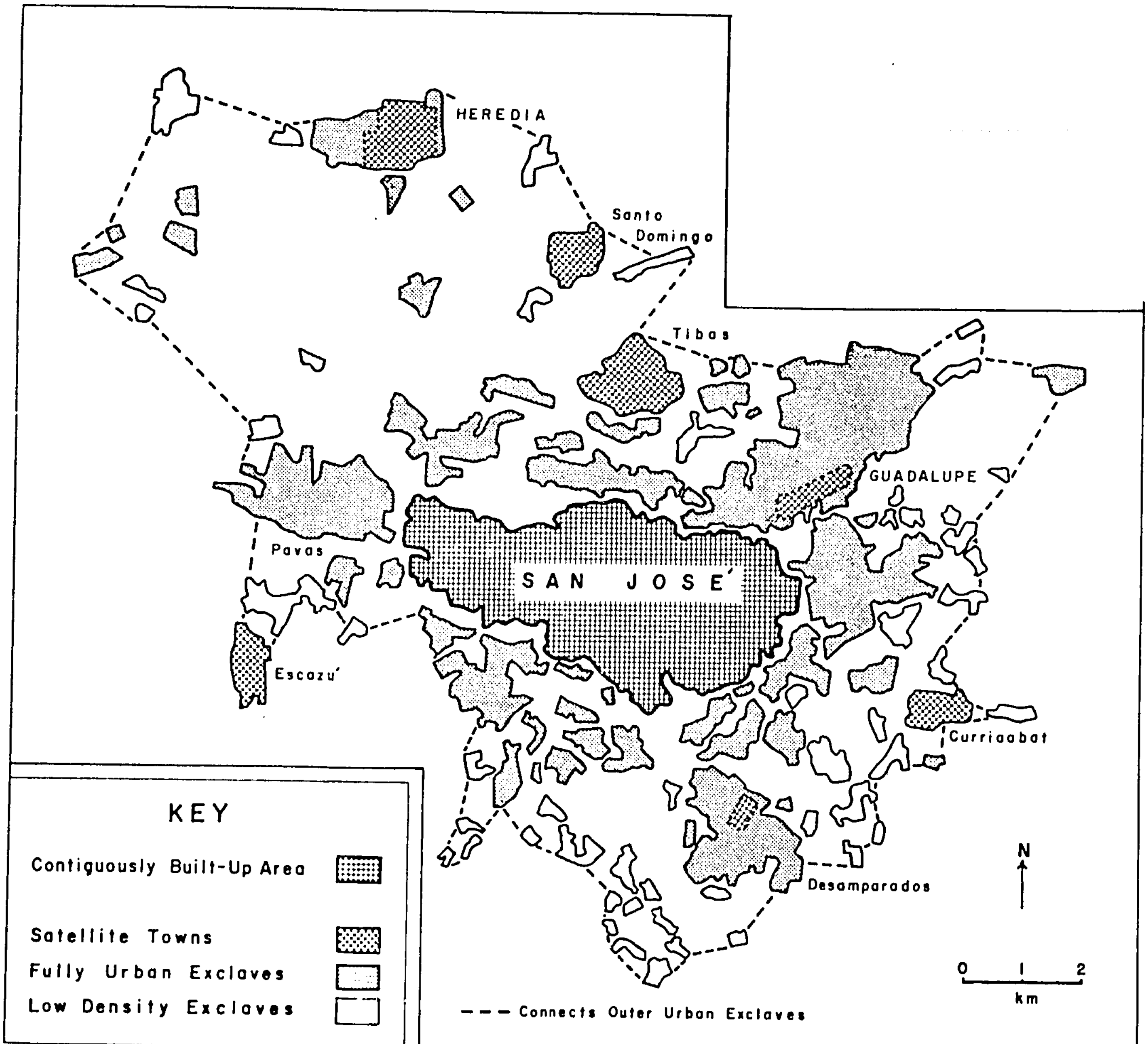


Figure 5-2: CONTIGUOUSLY BUILT-UP AREA AND URBAN EXCLAVES
San Jose, Costa Rica 1978

Described in the key to Figure 5-2 as the "fully urban exclaves" are those developments, both residential and industrial commercial, which were designed to be completely urban in character. Accordingly, they have all the customary improvements of paved streets, services, and display customary urban densities. They are completely urban in all respects except that of being contiguous with the central city. The total area of these "fully urban exclaves" of 2,752 hectares (Table 5-12) is approximately twice that of the central city itself and four to five times greater than the area occupied by the other two types of exclaves.

The "Low Density Exclaves" (referred to as Sparse Settlements on Table 5-12) are those areas consisting primarily of residential land which has grown up along roads and are a product of slow evolution rather than planning. There are 51 of these but they average only 14 hectares each (compared to the concentrated urban units average of 57 hectares each). They are generally characterized as having low building and population densities. They often continuously occupy road frontages. Access to the land behind these ribbons is frequently blocked. Coupled with small parcel size (and thus numerous land owners), much of this land is precluded from being employed for large, planned developments.

The broken line on Figure 5-2 connecting the Outer Urban Exclaves comprises an area which, if not built-up, is vacant land which could be affected by urbanization. For the northern, eastern, and southern sides of the city, most of the land involved is in relatively small parcels located in and around the exclaves. On the northwestern side of the city, the non built upon land occurs in large parcels, usually in the form of coffee plantations.

Further understanding of the nature of exclaves may be gained from examining their spatial relationships with the central city and with each other (see Table 5-13). In this analysis, the exclaves were perceived as being in "rings" outward

1978

Measurements	Number of Exclaves	Total Area (ha)	Average Area (ha)	Percent of Total Area	Average Distance Outward (m)*
EXCLAVES					
First Ring of Exclaves	15	1769	118	46.6	263
Second Ring of Exclaves	25	487	19	12.8	1,720
Third Ring of Exclaves	23	754	33	19.8	3,104
Fourth Ring of Exclaves and Beyond	36	790	22	20.8	3,752

* - Average distance of all units in ring from Contiguously Built-up San Jose.

Average distance between nearest neighbors = 268 m

Table 5-13: PATTERN ANALYSIS: SAN JOSE, URBAN EXCLAVES AND VACANT LANDS from the central city. As would be expected, the innermost ring (averaging only 263 meters from the city) was the largest in total and the components had the highest average area (118 hectares each). Included in this inner "ring" were large developments including Guadalupe, Pavas, and some of the large, planned development projects. Measurement of the average distance between nearest neighbors was also made. The average distance figure of 268 meters means little by itself but has potential as an index figure in later measurements of growth.

Plotting and measuring the evolution of the San Jose Metropolitan Area provides a history of urban expansion. It also permits a better understanding of the process of the conversion of land from rural to urban and provides a base for projecting trends of future growth.

The method employed to examine the growth of the city was an adaptation of standard change detection procedures. Aerial photographs from 1945 were compared with those of 1965 to determine the quantity and location of various types of change. The same procedure was followed for a second set of dates, 1965 to 1978.

For both these intervals, three types of change were detected, plotted, measured and analyzed (see Table 5-14). A series of maps indicates the location and patterns (Figures 5-3 through 5-8).

To provide a base for comparison, the first step in the measurement process was to delimit the boundary of the contiguously built-up area of San Jose in 1945. Delimiting the contiguously built-up area as tightly as possible resulted in an area of 715.3 hectares. That figure is somewhat lower than the 1,066 hectares reported by INVU in its publications largely as a result of not including Guadalupe and San Pedro. These former satellite towns are included under the heading "cores of satellite towns" in Table 5-15 and are part of the 221.1 hectare figure.

Type and Period of Change	Number of Exclaves	Total Area (ha)	Mean Exclave Area (ha)
1945 to 1965			
Agriculture to Built-up	96	1,552.9	16.2
Agriculture to Transition	38	298.8	7.9
Transition to Built-up	19	289.3	15.2
Total 1945-'65	153	2,141.0	14.0
1965 to 1978			
Agriculture to Built-up	131	1,661.7	12.7
Agriculture to Transition	61	806.9	13.2
Transition to Built-up	32	286.1	8.9
Total 1965-'78	224	2,754.7	12.3

Table 5-14: RURAL TO URBAN CONVERSION: AGRICULTURAL LAND TO BUILT-UP; SAN JOSE AND EXCLAVES

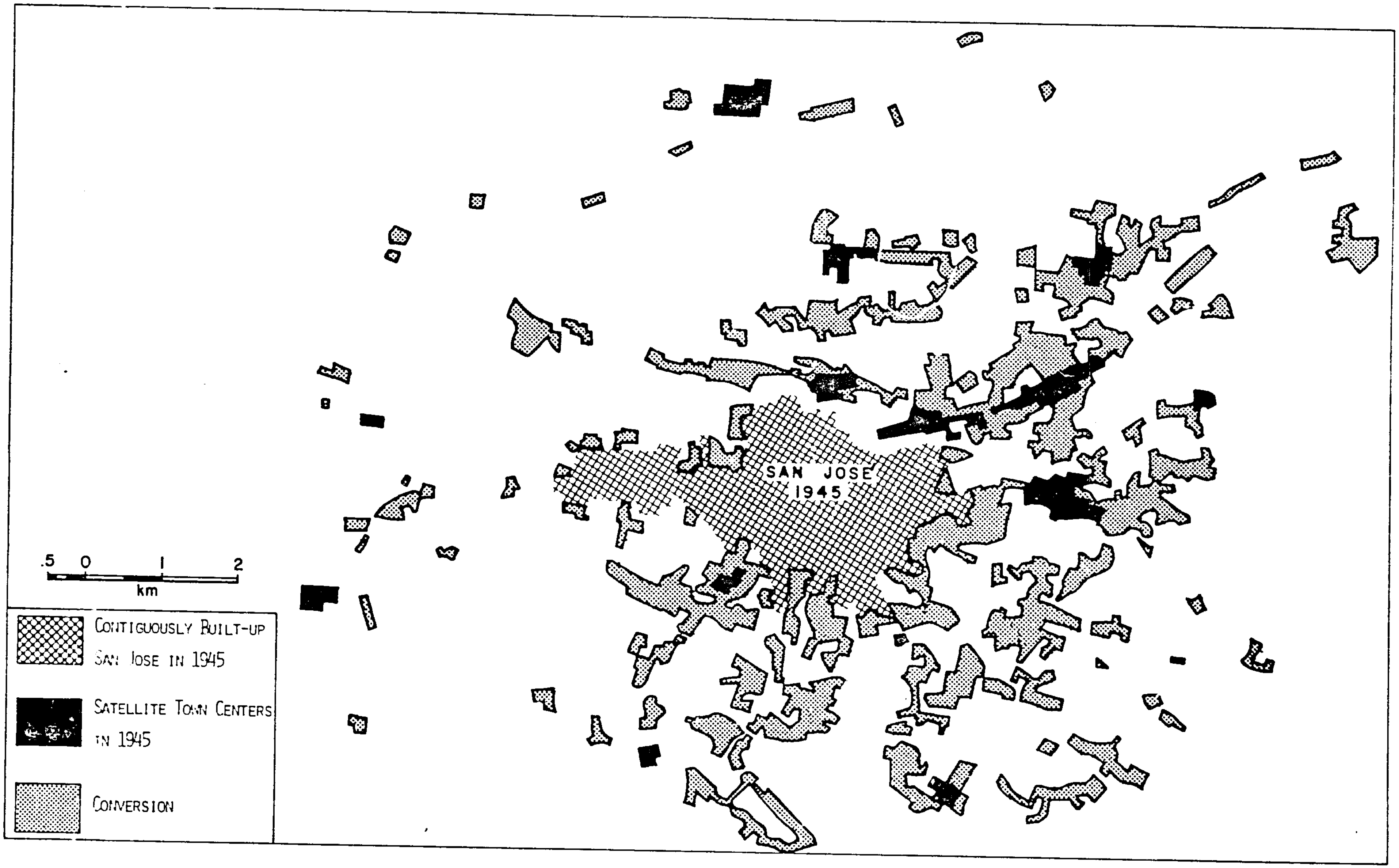


Figure 5-3: RURAL TO URBAN CONVERSION: AGRICULTURAL TO BUILT-UP 1945 TO 1965
Area Metropolitana de San Jose, Costa Rica

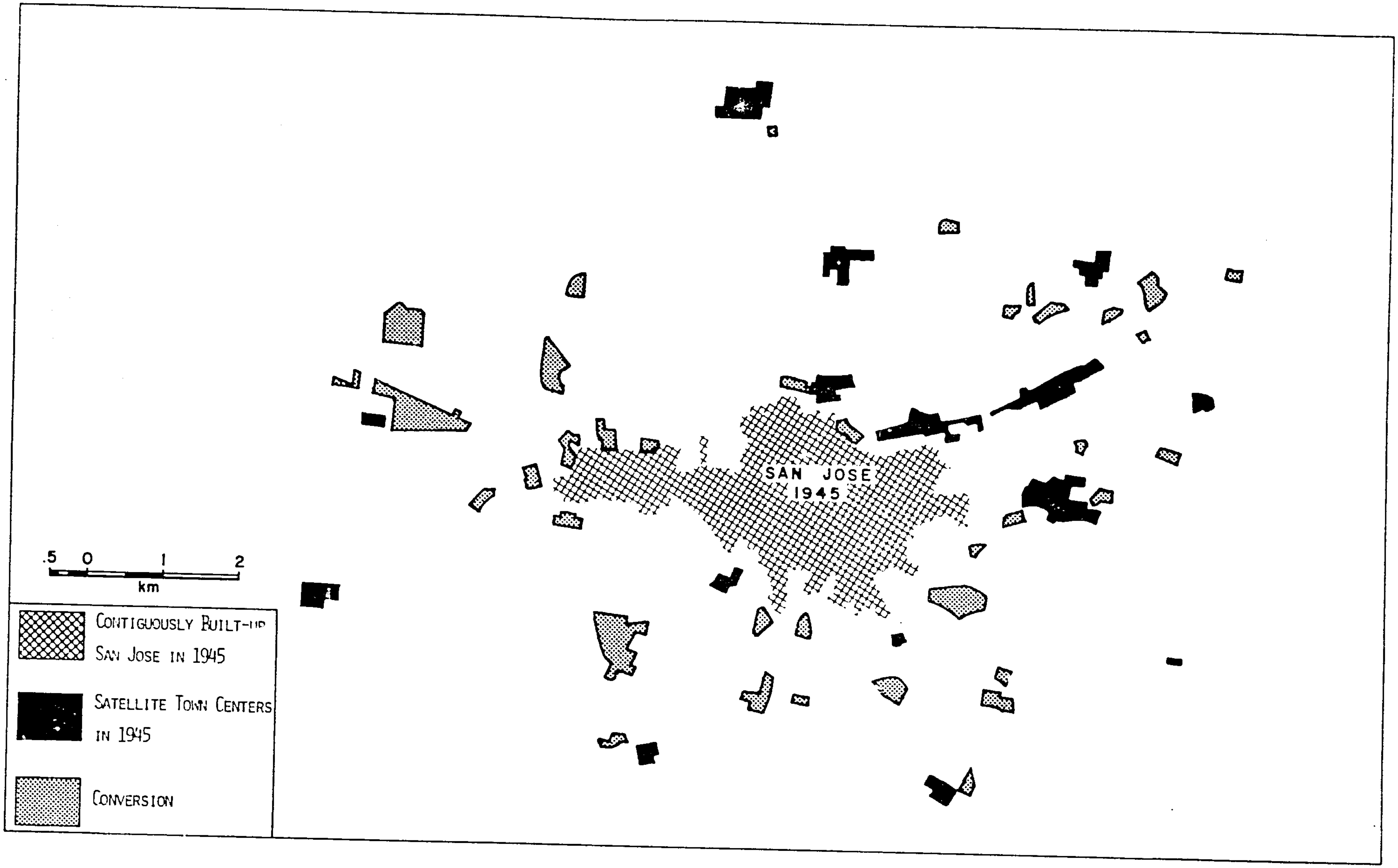


Figure 5-4: RURAL TO URBAN CONVERSION: AGRICULTURAL TO TRANSITION 1945 TO 1965
Area Metropolitana de San Jose, Costa Rica

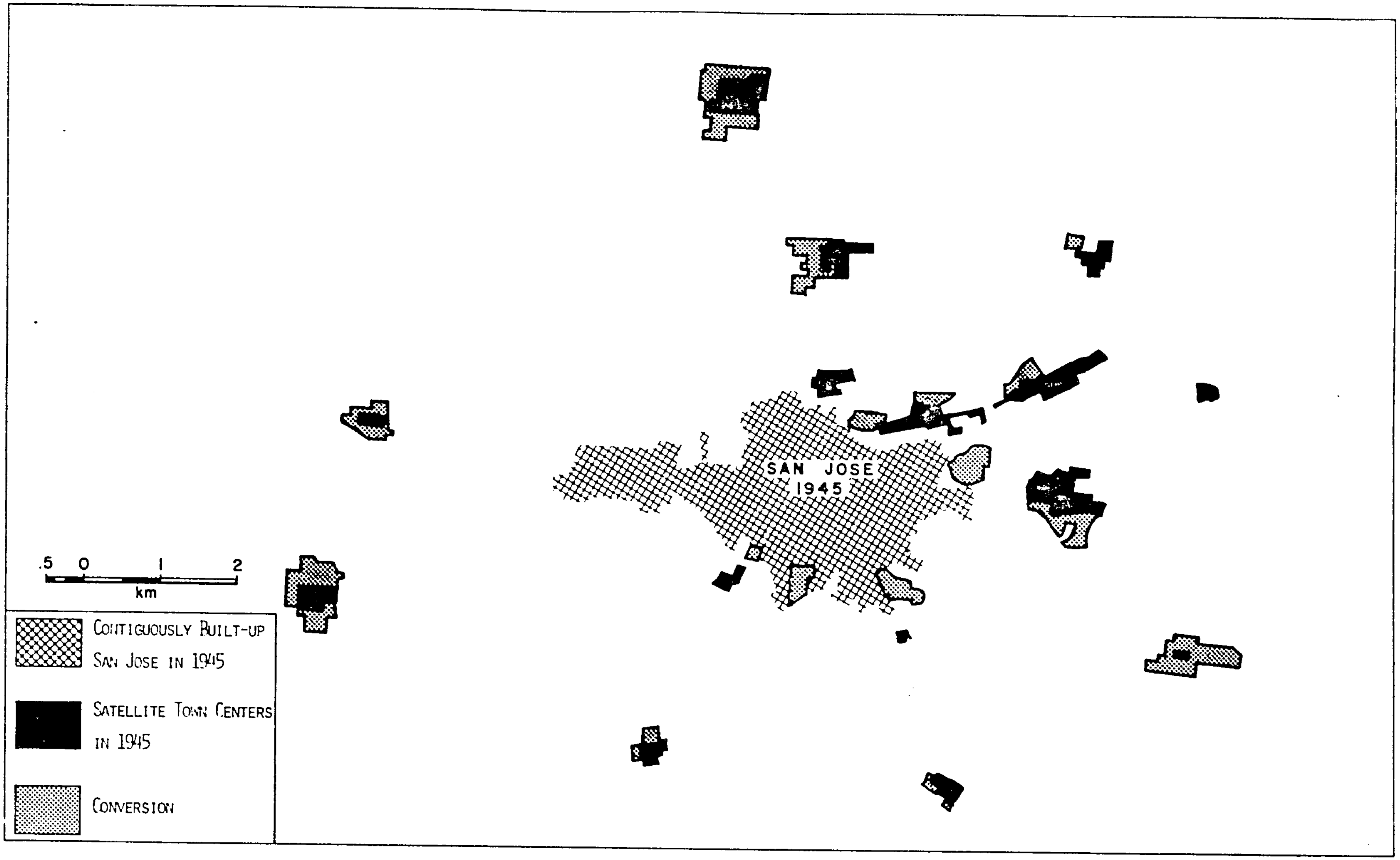


Figure 5-5: RURAL TO URBAN CONVERSION: TRANSITION TO BUILT-UP 1945 TO 1965
Area Metropolitana de San Jose, Costa Rica

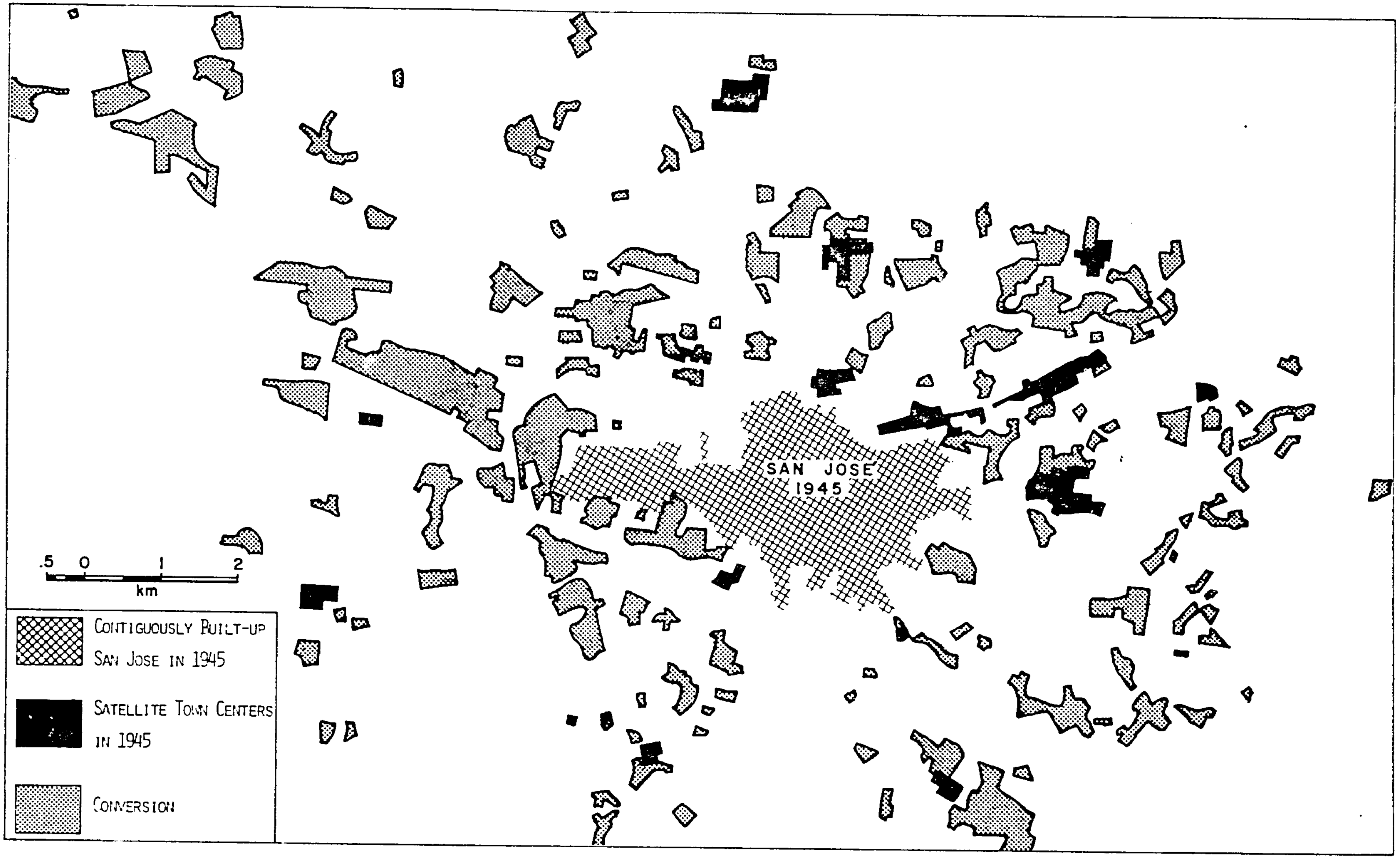


Figure 5-6: RURAL TO URBAN CONVERSION: AGRICULTURAL TO BUILT-UP 1965 TO 1978
Area Metropolitana de San Jose, Costa Rica

Figure 5-7: RURAL TO URBAN CONVERSION: AGRICULTURAL TO TRANSITION 1965 TO 1978
Area Metropolitana de San Jose, Costa Rica

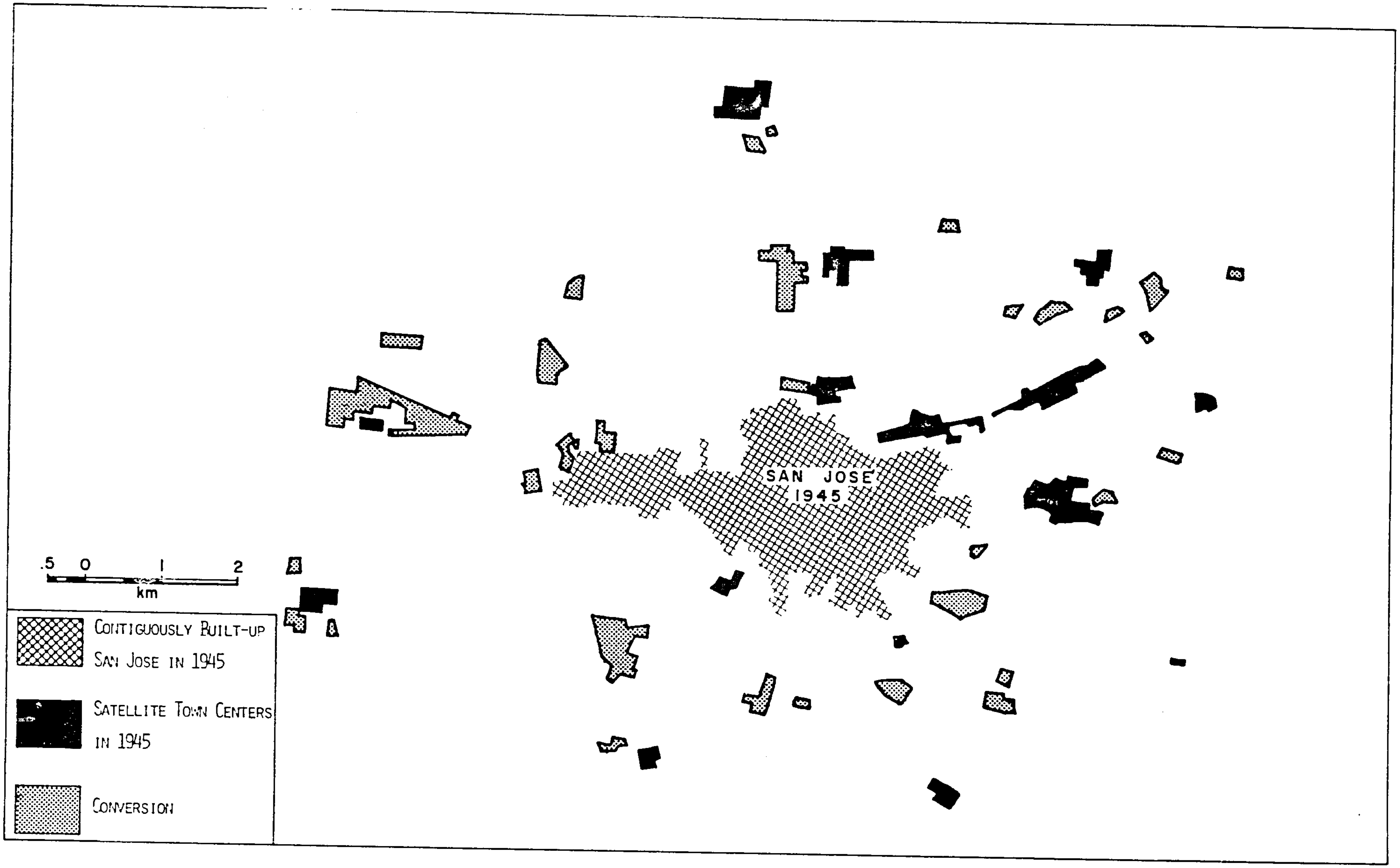


Figure 5-8: RURAL TO URBAN CONVERSION: TRANSITION TO BUILT-UP 1965 TO 1978
Area Metropolitana de San Jose, Costa Rica

Unit	Area (ha)
San Jose	715.3
Cores of Satellite Towns	221.1
Total	936.4

Table 5-15: AREA OF CONTIGUOUSLY BUILT-UP SAN JOSE AND CORES OF SATELLITE TOWNS IN 1945

Photographs for both pairs of dates were then examined to identify and plot the three types of change. Each type is reported on a separate thematic map. It is significant to note that the mapping procedure consisted of the direct plotting of the types of change; it was not necessary to make separate land use maps for each date as a preliminary step to making temporal comparisons. The map compilation process was thus a dynamic one. The technique served the purpose well and could be profitably employed in future monitoring studies.

The process of urban conversion is always in motion and ideally should be constantly monitored. When change was examined only between two static moments along a temporal continuum much of the intervening activity was obscured. This is well demonstrated by the data (Table 5-14) in which most of the total change is classed as being a conversion of land directly from rural to urban. In many instances during the change interval, there were surely intermediate stages of conversion of land from agricultural to transition and from transition to urban. Another way of analyzing the urbanization process is to consider that the conversion from agriculture to transition has probably occurred during the latter part of the study time span while most of the conversion from transition to built-up probably took place during the early part of the period.

Clearly, metropolitan growth was greater in the 13-year 1965 - 1978 period than it was in the 20 year 1945 - 1965 period. For the earlier period, 153 polygons (exclaves) of change were recorded while the later period witnessed 224 polygonal change. Areas also were greater with 2,754.7 hectares compared to 2,141.0 hectares. A much larger mean size of conversion of land from agriculture to transition in the 1965 - 1978 period (13.2 hectares in 1965 - 1978 compared to 7.9 hectares in 1945 - 1965) was a result of large urban projects in rural areas. Some of these are INVU housing projects.

As would be expected, another significant difference between the two map series is that the polygons of change for the 1945 - 1965 period were much nearer to the city than were those of the latter period. They also were adjacent to the satellite towns. In both instances, growth at the periphery of established units was greater than that in the open countryside probably. This growth pattern probably reflects the availability of paved roads and other urban services.

Spatial distribution of the patterns also varied for the two time periods. For the 1945 - 1965 period, growth was in a roughly circular pattern all around the city and especially toward the smaller, existing towns on the southern and eastern sides. A marked shift is apparent for the 1965 - 1978 period to a linear pattern along a northwest to southeast axis. Demonstrated here is the impact of the new highway (Autopista) to the International Airport (and its improvement beyond) and the section of the Autopista from Curridabat toward the east. In a broader sense, the stretching out of the urban developments of the entire corridor of the Meseta Central is manifested by this development of a linear urban pattern. This is especially apparent in Figures 5-7 and 5-8 showing the recent developments in conversion of agricultural to land in transition and the conversion of land in transition to built-up land. The nature of the available land for development is also manifested. Early developments on the south side of the city have already consumed most of the readily built-upon level land in the narrow valleys issuing forth from the hills. Newer developments (to the northwest), essentially conversions of prime coffee-raising agricultural land, were built on land with few topographic impediments. Once urban conversion began in this area, with its attendant provision of urban surfaces, its value for urban usage increased. Further, once the process of subdividing the coffee plantations began, the precedent was established for further conversion to urban usage.

Another step in the analysis of metropolitan San Jose was the delimitation of the urbanized area. This section deals with a method of delimitation using aerial photo interpretation methods and was a prerequisite to detecting land use change.

Because no universally accepted method exists to provide a systematic delimitation of urbanized areas using aerial photo interpretation methods, it was necessary to develop a set of special rules. Considerations in developing the method were: 1) that the concept of contiguity be adhered to as closely as possible; 2) that the number of urban exclaves and enclaves be reduced to as small a number as possible; 3) that delimitation procedure rules be simple and rational; 4) that they be compatible with the generally available scales of aerial photography and maps; and 5) that the system be as objective as possible and capable of replication by any researcher with an expectation of achieving approximately the same results. The rules employed were:

1. boundaries must follow easily identified linear features: railroads, roads, rivers, power transmission lines, etc.,
2. the minimum size urban satellite is five hectares,
3. urban areas include urban land uses at the edge of the contiguous mass such as land used for recreation or land in the process of transition to rural to urban,
4. to be considered as urban, an area must have dual transportation route access. (This precludes inclusion of narrow strings of development radiating out from the city along major roadways), and
5. utilizing gravity model theory, small urban satellite areas may be subsumed into a greater urbanized boundary when separated by no more than 500 meters from massive urban areas.

The boundaries of the urbanized area of San Jose for 1945, 1965, and 1977 appear on Figure 5-9. The 1945 contiguously built-up area is shown by cross-hatching indicating that it is the base date; the 1965 outlying urbanized communities, such as Escazu, existed as discrete places in 1945, but did not become part of the contiguous urban mass until 1977.

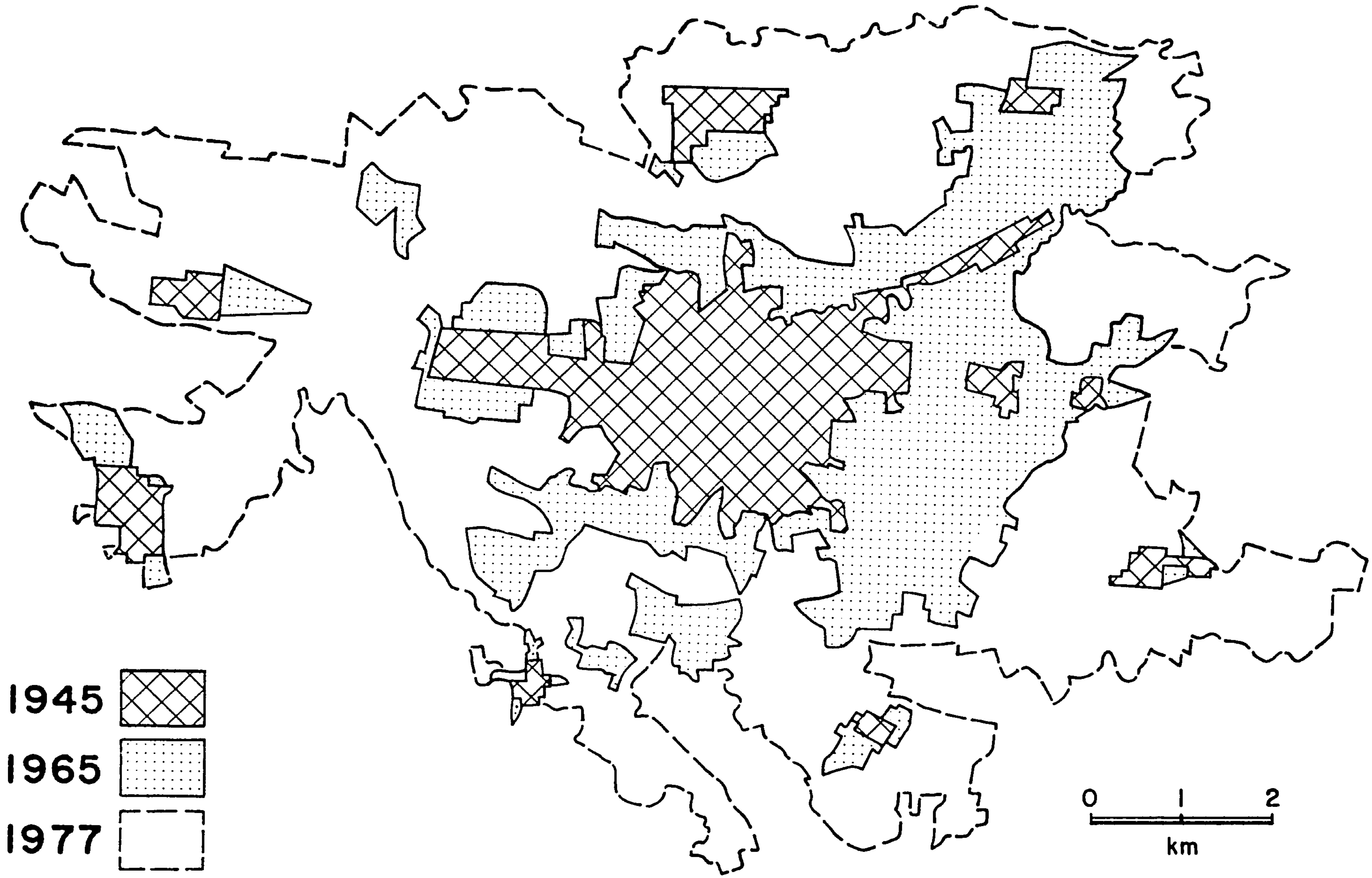


Figure 5-9: EXPANSION OF THE URBANIZED AREA
San Jose, Costa Rica

The areas of urbanized land for each date were measured using an electronic planimeter. The results (Figure 5-10) reveal that the urbanized area almost tripled between 1945 and 1965 and more than doubled from 1965 to 1977. Considering that urban growth has not been halted and that several areas with urban characteristics exist beyond the 1977 line, there is a strong likelihood that the total urbanized area will make another significant increase in the near future.

A sample from the southern side of San Jose may serve as a detailed example of the land use conversion process from rural to urban. Changes in this area were recorded between the land use classes of:

1. land remaining in viable agricultural usage,
2. abandoned agricultural land,
3. land showing visible evidence of rural to urban conversion,
4. land in urban use.

The types of change possible are represented in the matrix seen in Figure 5-11. The diagonal reprsenting no change possible bisects the matrix. The most likely types of change are seen in the upper part with the full theoretical conversion sequence placed in a shaded pattern. Other direct changes are indicated and occur frequently in a real situation. In some instances, however, a full conversion sequence may occur, but may escape observation if the dates of the photography are too far apart.

Provisions were made for reverse changes (from urban to rural) in the lower half of the matrix. The least likely ones are in parenthesis. Only a conversion from abandoned to active agriculture was very likely to happen and did in some instances in the San Jose area where once abandoned coffee plantations were revived, usually in response to a commodity price rise. Mapped examples appear in Figures 5-12 and 5-13. Visual comparisons of photographs of the same werea are readily made.

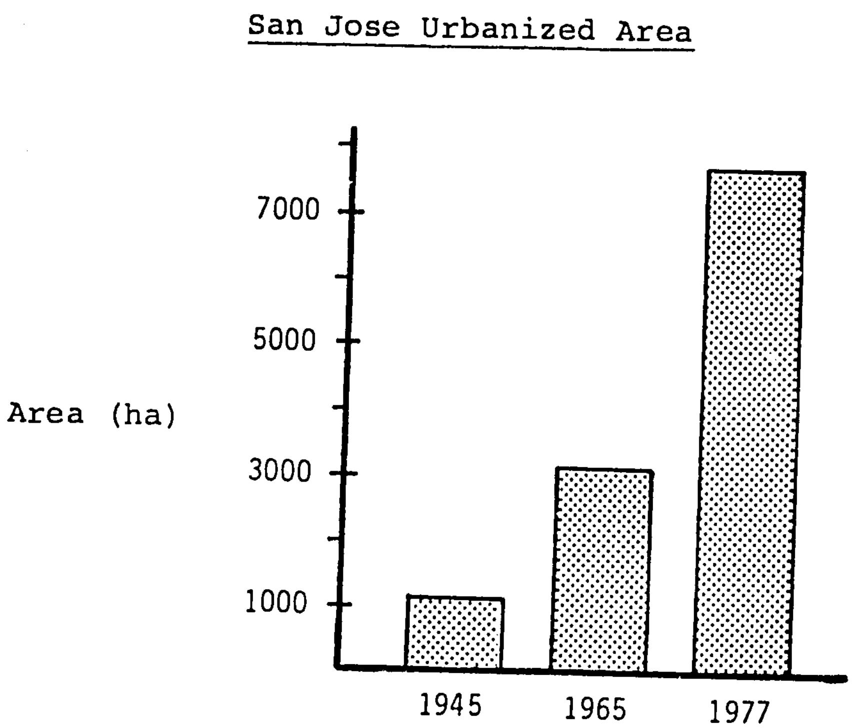


Figure 5-10: SAN JOSE URBANIZED AREA

Second Date

Process Stages / Initial Date	1	2	3	4
1	No Change	1-2	1-3	1-4
2	2-1	No Change	2-3	2-4
3	(3-1)	(3-2)	No Change	3-4
4	(4-1)	(4-2)	(4-3)	No Change

[shaded cells] - Theoretical conversion sequence

( ) - Highly unlikely conversions

Process Stages

1 - Land remaining in viable agriculture

2 - Abandoned agricultural land

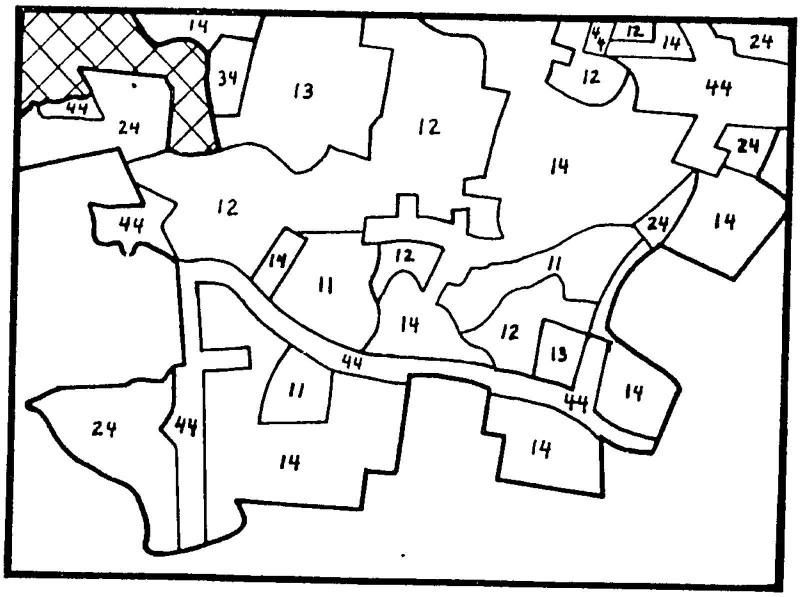
3 - Land showing visible evidence of rural to urban conversion

4 - Land in urban use

Figure 5-11: MATRIX OF POSSIBLE TYPES OF LAND-USE CHANGE

1945

1965



1945 to 1965 CONVERSION

LAND USE STAGE CONTINUUM*

1. ACTIVE AGRICULTURE
2. ABANDONED AGRICULTURE
3. TRANSITION TO URBAN
4. URBAN

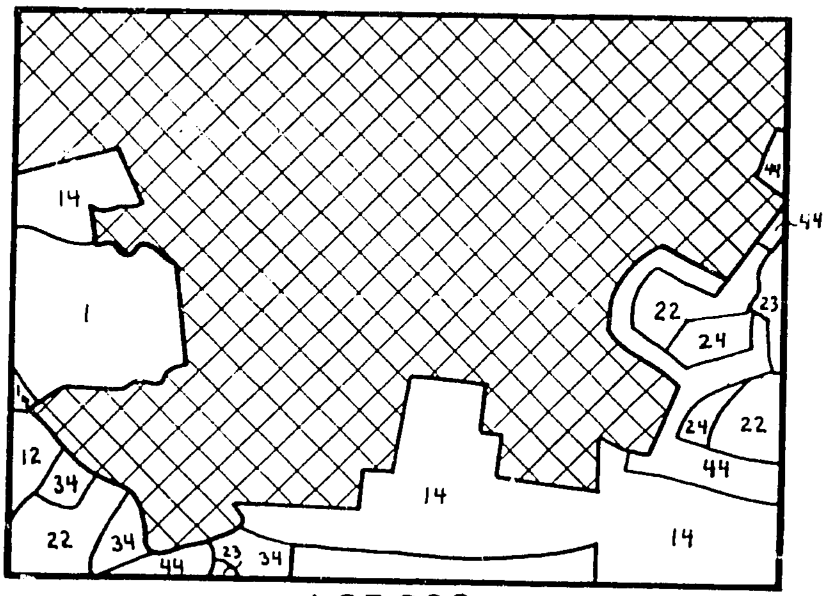
1:25 000

Each conversion polygon contains two numerals, indicating the initial and subsequent stages.

Figure 5-12

1965

1977



1:25000

1965 to 1977 CONVERSION

LAND USE STAGE CONTINUUM*

1. ACTIVE AGRICULTURE
2. ABANDONED AGRICULTURE
3. TRANSITION TO URBAN
4. URBAN

*Each conversion polygon contains two numerals, indicating the initial and subsequent stages.

Figure 5-13

5.3.3 Urban Growth Projection

Matrix modeling methods were used for both decription and projection of the spread of urbanization in the Meseta Central/San Jose metropolitan area. The models and techniques employed are presented and results discussed in more detail in Technical Annex 3.

Appropriate aerial photography and supporting statistical detail was available for three dates: 1945, 1965, and 1977. These served as data points for this study. Landsat satellite data was available for 1975, but aerial photography and statistical data were incomplete for this year. Similarly, although new aerial photography and Landsat data were available in 1978, the required statistical data was unavailable at the time of this study.

Four general classes of land use were considered in this analysis:

1. agricultural land (land continuing in viable agricultural use),
2. abandoned agricultural land (land previously in agriculture but showing no signs of current or recent use),
3. land in conversion (land showing viable evidence of rural to urban conversion), and
4. urban land (built-up and related land).

Changes in each of these categories were compared in a matrix format for paired data points (Figure 5-14). Since this particular analysis effort concentrated on the agriculturally-important Meseta Central and San Jose metropolitan areas, relatively little land fell into "forest" or other land use categories and these could be safely ignored.

At the present time, nearly 7,800 hectares of land in the Meseta Central are either already urbanized or are directly threatened by urbanization (reference Figure 5-9). Based on the

	Subsequent Date				
	1 Viable Agriculture	2 Abandoned Agriculture	3 Transition	4 Built-up	Sums For Initial Date
1 Viable Agriculture	element 11	12	13	14	---
2 Abandoned Agriculture	21	22	23	24	---
3 Transition	31	32	33	34	---
4 Built-up	41	42	43	44	---
Sums For Subsequent Date	---	---	---	---	Total

Figure 5-14 : MATRIX FORMAT

model presented in Technical Annex 3, approximately 46% of this entire area (3,575 hectares) will have converted from viable or transitional agricultural land to urban (built-up) land by the close of the 1965-1980 period.

5.3.4 Regional Resources Change Detection

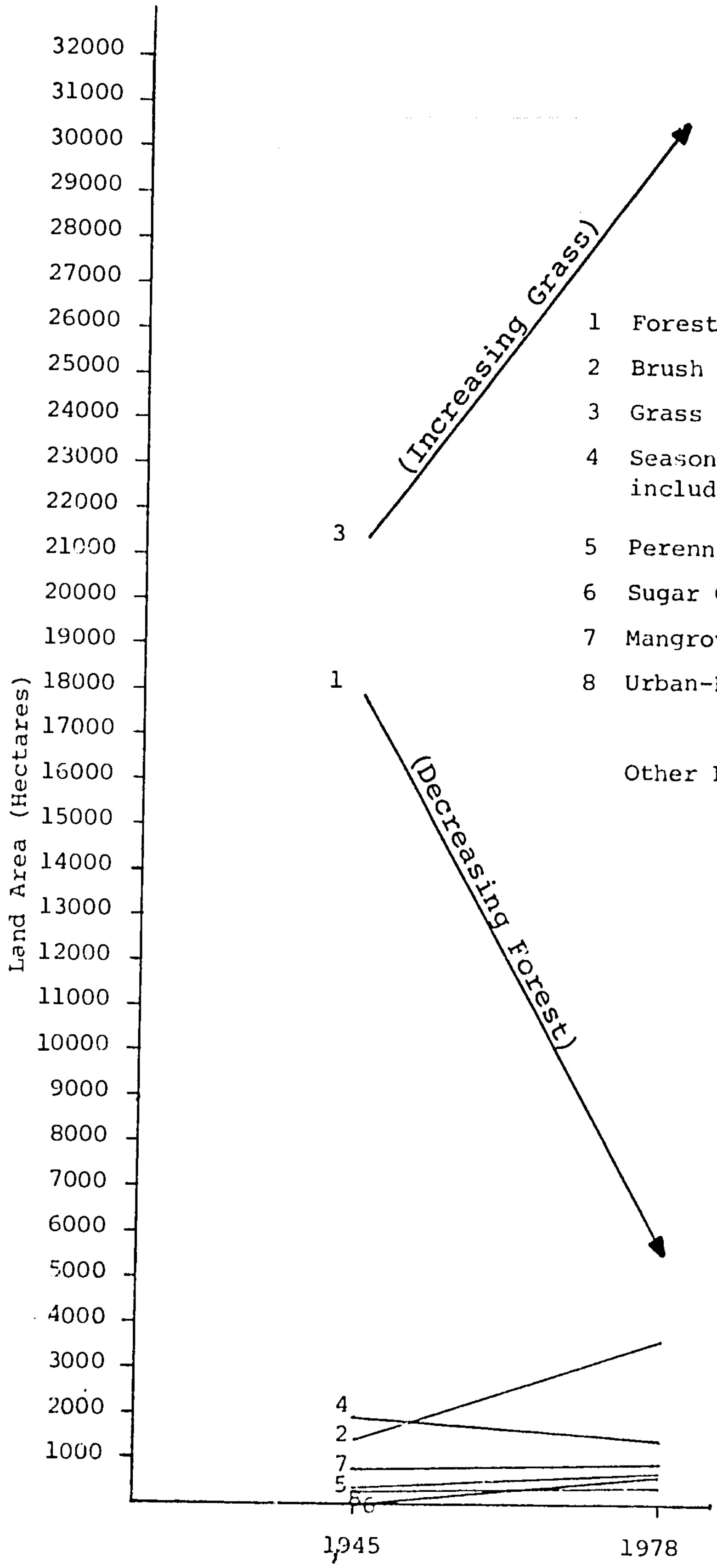
A test of the ability to detect change in regional land cover/land use was conducted on the area covered by the Barranca 1:50,000 map sheet, using 1945 and 1978 photography and the 1978 photo interpretation sample points employed in the Landsat accuracy test. Three sample cells were reselected because 1945 black and white photography was not available for the previously selected sample cells. The replacement cells were chosen in the same strata that the original cells represented and by the same variable probability selection procedure discussed in Section 5.1.3.2.

Table 5-16 displays a matrix showing the distribution of 1945 sample points on the horizontal axis and 1978 sample points on the vertical axis. Figure 5-15 displays a graph of the estmated hectares of change for eight cover types. It provides the estimated area of change and the difference as a percentage of the total map area as a (-) for a decrease in cover type area and (+) for an increase in cover type from 1945 to 1978. The "other land" category represents the cover types not encountered in the change detection sample. The seasonal agriculture category in Figure 5-15 includes rice. No sugar cane was observed in the 1945 sample areas. The major trends in land cover/land use change that can be derived from Table 5-16 and Figure 5-15 are:

1. In 1945, the total forest area encompassed an estimated 42% of the approximately 500 square kilometers shown on the Barranca map. In 1978, the remaining forest (primarily along stream courses) occupied only 15% of the map area. Fifty percent of the 1945 forest sample points were converted to grass (grazing land) by 1978,

1978 CIR Aerial Photography \ 1945 Black & White Aerial Photography	Forest	Brush With Trees	Grass	Rice	Other Seasonal Agriculture	Other Perennial Agriculture	Sugar Cane	Urban Residential	Mangrove	Inland Water	Barren Land	Total For 1978 Cover Type Sampled	Percent of Total For 1978 Cover Type Sampled
Forest	70	4	4	-	1	-	-	-	-	-	1	80	14.98
Brush With Trees	25	9	17	-	-	-	-	-	-	-	2	53	9.93
Grass	112	14	174	5	15	-	-	-	-	-	2	322	60.30
Rice	13	-	3	2	-	-	-	-	-	-	1	19	3.56
Seasonal Agriculture	1	-	3	-	6	-	-	-	-	-	-	10	1.87
Perennial Agriculture	-	-	3	-	1	3	-	-	-	-	-	7	1.31
Sugar Cane	1	-	5	1	3	-	-	-	-	-	-	10	1.87
Urban Residential	-	-	-	-	1	-	-	2	-	-	-	3	.56
Mangrove	-	-	1	-	-	-	-	-	16	1	-	18	3.37
Inland Water	-	-	3	-	-	-	-	-	-	1	1	5	.94
Barren Land	3	-	1	-	-	-	-	-	-	-	3	7	1.31
Total for 1945 Cover Type Sample	225	27	214	8	27	3	0	2	16	2	10	534	
Percent of Total for All 1945 Cover Types Sampled	42.13	5.06	40.08	1.50	5.06	.56	0	.38	3.0	.38	1.87		

Table 5-16: BARRANCA CHANGE DETECTION SAMPLE DISTRIBUTION



		1945 Ha.	1978 Ha.	Change of Total Land Area
1	Forest	17,881	5,640	-27.2
2	Brush with Trees	1,449	3,654	+ 4.9
3	Grass Dominant	21,417	30,508	+20.2
4	Seasonal Agriculture including Rice	1,947	1,452	- 1.1
5	Perennial Agriculture	417	754	+ .75
6	Sugar Cane	0	672	+ 1.50
7	Mangrove	764	930	+ .37
8	Urban-Residential	323	404	+ .18
		44,198	44,014	
	Other Land	804	990	
		45,004	45,004	

Figure 5-15: BARRANCA LAND COVER ESTIMATE OF CHANGE FROM 1945 TO 1978

with an additional eleven percent converted to brush and trees, and 6% converted to rice.

2. In 1945, 5% of the total map area was covered by brush and trees. This class now occupies 10% of the Barranca map area. Fifty-two percent of the 1945 brush and trees sample points converted to grass cover and 15% converted to forest cover as of 1978.

3. In 1945, 40% of the Barranca map area was in grass cover compared to 60% in 1978. Eight percent of the 1945 grass sample is now in forest and brush with tree cover. Four percent of the 1945 grass converted to rice and other seasonal and perennial agriculture (e.g., vegetables, fruit trees), 2% converted to sugar cane.

The remaining cover types (agriculture, urban, mangrove, and other lands) contribute only a small percentage of the overall land cover change since 1945. The sample (selected on the basis of 1978 cover type proportions) tends to be biased to the forest and grass covered areas. The estimates of change for rice (2.1% increase) and other seasonal agriculture (3.2% decrease) may not be representative due to this bias. However, from a visual assessment of the 1945 photography, the rice producing land appeared to be much more widely distributed throughout the Barranca map area in 1945 with many small fields occupying the land that was cleared of forest some time prior to 1945. The present rice producing land in 1978 generally occupies large fields (primarily floodplain) and are fewer in number.

Photo 5-1 depicts 1945 land cover/land uses around the City of Esparza (E). Dry rice fields (R) and grazing land (G) were common agricultural uses in this area in 1945. Forested land (F) was present north of Esparza as seen in the top portion of the photo. Photo 5-2, a color infrared aerial photo taken in 1978, shows considerable change in land use as compared to Photo 5-1. The city limits of Esparza (E) have expanded primarily to the north and much of the rice and pasture land has since converted to sugar cane (S). The forest north of Esparza in 1945 has been almost entirely removed and now supports only marginal grazing uses (low forage availability). Photo 5-3 reveals the wide

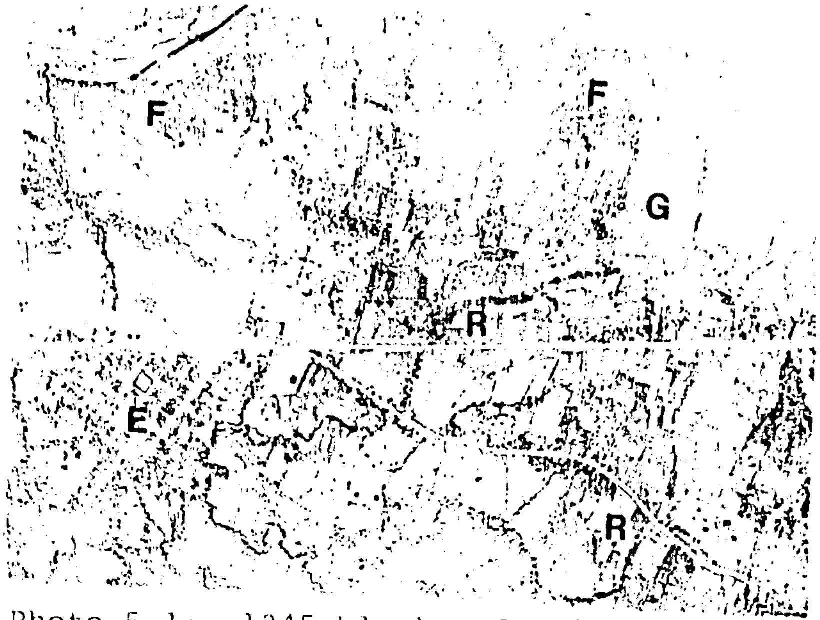


Photo 5-1: 1945 black and white aerial photograph of land cover/land use around Esparza.

Photo 5-2: 1978 color infrared aerial photograph of land cover/land use around Esparza. Refer to text for explanation of symbols.

Photo 5-3: 1945 black and white aerial photograph of land cover/ land use approximately eight kilometers southeast of Esparza.

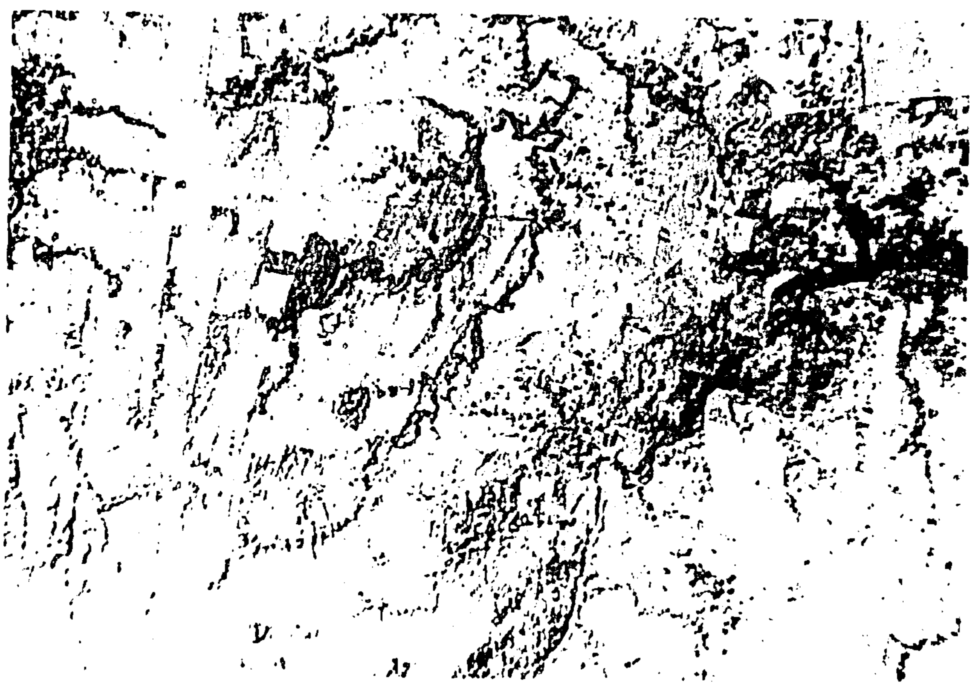


Photo 5-4: 1978 color infrared aerial photograph of land cover/land use approximately eight kilometers southeast of Esparza.

distribution of dry land rice fields (R) which was characteristic of the Barranca study area in 1945. Sizable blocks of virgin forest land were also present in 1945. Photo 5-4 reveals the land cover condition for 1978. Some of the same fields that were producing rice and other seasonal agricultural crops in 1945 continue in that use. The forest has been severely depleted within the Barranca map area as well as in the surrounding provinces of Guanacaste, Puntarenas, Alajuela and San Jose.

In addition to the photo sampling test described for the Barranca region, an attempt was made to compare the forest cover existing in a portion of Costa Rica in 1944 with that identified in Landsat satellite data in 1975, 31 years later. In 1944, black and white (panchromatic) aerial photography at a nominal scale of 1:60,000 was collected over most of Costa Rica. This photography formed the base for the "forest" area interpretation shown in green tint on the existing 1:200,000 scale San Jose map sheet. A portion of this map is shown in Figure 5-16, together with the results obtained from a digitally interpreted 1975 Landsat frame. It is immediately evident that there has been a major decrease in forest cover.

The map shown in Figure 5-16 includes approximately 1,354 square kilometers of land area. In 1944, 429 square kilometers or about 32% of the total area was in forest. The Landsat analysis indicates that in 1975 only 100 square kilometers or about 7% of the total area remained in forest. This 329 square kilometer loss represents a decrease in forest area of nearly 77% since 1944.

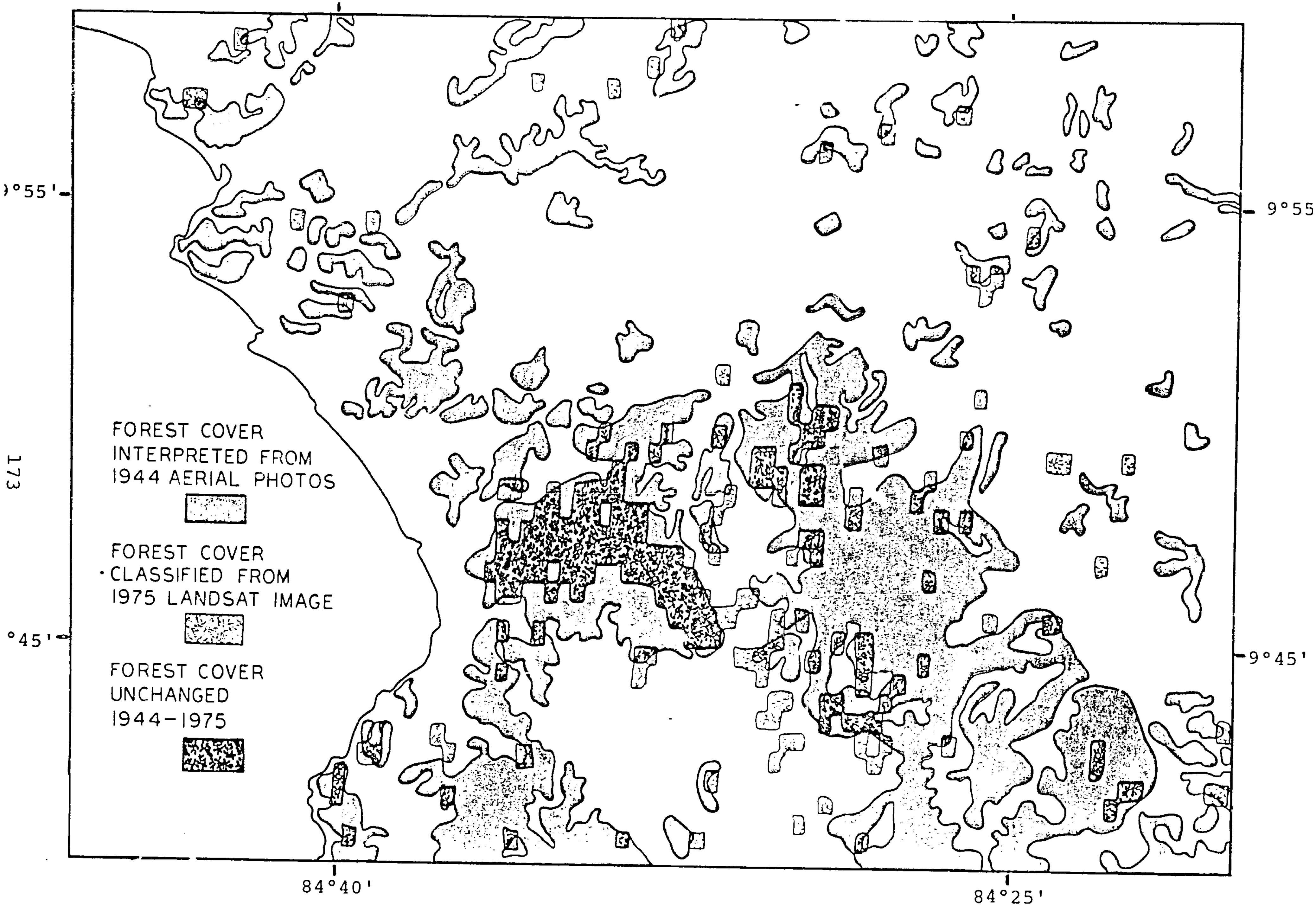


Figure 5-16: FOREST AREA COVERAGE AS DERIVED FROM 1944 PHOTO INTERPRETATION AND 1975 LANDSAT COMPUTER-ASSISTED CLASSIFICATION

6.0 RESOURCE SURVEY ECONOMICS - A COST-EFFECTIVE COMPARISON

Studies to determine the appropriateness of remote sensing technology for resources survey in developing countries have traditionally been based on two separate types of analyses: cost-benefit and cost-effective. The mechanics of these analyses techniques, their strengths and their weaknesses, have been discussed extensively in the published literature (22-25). Cost-benefit analysis, at least as applied to earth resources information systems, is normally concerned wih identifying the costs associated with collecting and processing this "more complete" information and estimating the net social benefits that will derive from the "better decisions" that will, presumably, be made. Cost-effectiveness analysis, on the other hand, concerns itself with comparing alternative methods to accomplish a given task or tasks that have been exogenously defined as "required". The Costa Rican government has determined that better and more complete resources information is urgently required in the near term, thus a cost-effectiveness analysis would appear appropriate in this case.

The question that arises is "cost-effective as compared to what?" There has been little inventory work done in Costa Rica in recent years, and none of the type now required. Accordingly, little reliable data exists concerning costs, rates of production, or accuracy levels with current comparable inventory techniques.

6.1 Level II and III Land Cover Maps at 1:50,000 Scale

In the absence of published data or written records, Costa Rican professionals with resources mapping experience were asked to estimate time, cost and levels of effort required to produce land cover maps at a scale of 1:50,000 detailed at Levels II and III, using 1:30,000 scale panchromatic photography as the principal data source. This type of photography has been employed in Costa Rica in the past for resources surveys on limited areas. These estimates were then averaged and reviewed with the group, and form the basis for the "traditional method" cost calculations presented here. These figures are comparable with those obtained on similar projects in other countries and appear to be both reasonable and valid.

These data are presented in Table 6-1, together with cost estimates of similar resource map production using techniques employed on the pilot project. The costs and levels of effort shown are minimal for each alternative, assume production-level efficiencies and no delays due to weather. The data indicate that, using 1:4[illegible],000 scale color infrared photography as the principal data source, resource maps at 1:50,000 scale can be produced at half the cost and in half the time previously required in Costa Rica.

6.2 Level I Land Cover Maps at 1:200,000 Scale

Level I forest and land cover maps at scales of 1:200,000 and smaller have been previously prepared in Costa Rica. Unfortunately, reported costs of producing these maps vary widely, apparently as a function of the levels of aggregation and assumptions that the authors involved were willing to accept. In the absence of reliable data, cost comparisons with previous resource mapping at this scale in Costa Rica would be relatively meaningless.

The cost and work items required to product land cover maps at 1:200,000 scale of Costa Rica from Landsat digital data are summarized in Table 6-2. Although these costs are shown on a per map sheet basis, it should be noted that a single frame of Landsat data covers approximately 34,000 square kilometers. This is equivalent in area to nearly three 1:200,000 map sheets of the type produced in Costa Rica. As the boundaries of Landsat images and map sheets will seldom coincide exactly, a reasonable estimate is that two map sheets at this scale may be produced

Data Type	CIR transparencies @ 1:40,000	B/W Pan prints @ 1:30,000
Material[1]	1/10th roll CIR (20 frames) @ $500/roll. . . . . $ 50	1/5th roll Pan (40 frames) @ $130/roll. . . . . $ 26
Data Collection[2]	1 ea. 2 hr. mission (minimum time) @ $100/hr. . . . . $ 200	1 ea. 2 hr. missions (minimum time) @ $100/hr. . . . . $ 200
Data Processing	1/10th roll @ 250/roll, including calibration & shipping . . . . $ 25	1/5th roll @ $100/roll, including shipping . . . . $ 20
Photo Interpretation $ Analysis	Material set-up and work preparation @ 20 hrs; PI, edge matching, cross checking and revisions @ 80 hrs. 100 hrs. @ $4.80 . . . . $ 480	Photo interpretation, analysis, material set-up, and field checking combined. 40 frames @ 24 hrs/frame 480 hrs. @ $4.80 . . . . $2304
Field Checking[3]	40 hrs. @ 4.80 . . . . $ 192	Included in above
Compilation & Scribing (Land Cover data)	Transfer from 1:40,000 photos to 1:50,000 map base @ 40 hrs. Scribing and labeling @ 60 hrs. 40 hrs. @ 4.80 plus 60 hrs. @ $2.90. . $ 366	Transfer from 1:40,000 photos to 1:50,000 map base @ 80 hrs. Scribing and labeling @ 60 hrs. 80 hrs. @ $4.80 plus 60 hrs. @ $2.90 . . $ 558
Compilation & Scribing (Auxiliary Data)	Drainage, watershed, soils, geology, slope, misc., from existing maps, photos, and data sources 80 hrs. @ $4.80 plus 100 hrs. @ $2.90. . . . . $ 674	(Same as for CIR) 80 hrs. @ $4.80 plus 100 hrs. @ $2.90. . . . . $ 674
TOTAL COST[4] (to produce one scribed, reproducable master map of land cover with associated overlays)	$1987	$3782
TIME REQUIRED	420 hours —— 10.5 man-weeks	800 hours —— 20 man-weeks

(1) Does not include costs of scribecoat and related materials, presumed equal for either alternative.

(2) Assumes weather is not a factor in data collection and that re-flights are not required.

(3) Does not include costs of field transportation, per diem, or related costs, presumed equal for either alternative.

(4) Labor costs are based on Costa Rican scales for resource professionals and draftmen. Total costs and level of effort shown are for comparison of alternatives only. They do not include allowance for facilities, overhead, supervision, equipment or similar items and thus do not represent total costs of resources survey and mapping operations in Costa Rica.

Table 6-1: COST PARAMETERS. LEVEL II AND III LAND COVER MAPS (COSTA RICA). 500 km^2 @ 1:50,000 (ONE MAP SHEET)

Data Type	Landsat Digital	(1 map sheet)	Added Cost	Total Cost
Material[1]	Landsat Computer Tape (CCT)	$ 200	$ -0-	200
Data Collection[2]	NASA (no charge beyond that for the CCT).	-0-	-0-	-0-
Data Processing[3]	Includes Training Set Selection; Clustering Statistics; Class Combination; Maximum Likelihood; Symbol Assignment and Scaling of Printer Output; Photo Verification; Stratification; Cover Class Grouping or Strata Mapping; Classification Inspection; Geometric Control Point Selection; Geometric Correction; Scaling and Output of Final Line Printer Maps	6,500	2,000	8,500
Data Analysis[4]	Interactive with data processing; 100 hrs. @ $4.80 plus $2000 travel to U.S. facility with three weeks per diem	2,480	830[6]	3,310
Aggregation and Scribing (Land Cover data)	Aggregation @ 20 hrs.; scribing and labeling @ 60 hrs.; 80 hrs. @ $2.90	232	232	464
Aggregation and Scribing (Ancilliary data)	Drainage, watershed, soils, geology, slope, misc., from existing maps, photos and data sources; 80 hrs. @ $4.80 plus 100 hrs. @ $2.90	674	674	1,348
TOTAL COST[5]	(To produce one and two scribed reproducible master maps of land cover with associated overlays)	$10,086	$3,736	$13,822
TIME REQUIRED		9.5 man-weeks		17 man-weeks

(1) Does not include costs of scribecoat and related materials.

(2) Assumes weather is not a factor in data collection, that NASA will activate the satellite system as required over Costa Rica and that data quality permits CCT production.

(3) Typical costs to process in the U.S. at any of several facilities.

(4) Assumes Costa Rican professionals available to interact with data processing operators.

(5) Labor costs are based on Costa Rican scales for resource professionals and draftsmen. Total costs and level of effort shown are for comparison of alternatives only. They do not include allowance for facilities, overhead, supervision, equipment or similar items, and thus do not represent toal costs of resources survey and mapping operations in Costa Rica.

(6) Additional 40 hours @ $4.80 plus one week per diem.

Table 6-2: COST PARAMETERS. LEVEL I LAND COVER MAP (COSTA RICA) from each frame of Landsat data, provided that cloud cover in the image is not extensive.

6.3 Implications for Nationwide Resources Survey and Mapping

As noted on the earlier Demonstration Project and confirmed in this study, there is a definite, current and continuing requirement for two separate types of resources information in Costa Rica. Regional land cover maps at 1:200,000 scale and Level I detail are needed to define the extent and general condition of the forest resource and monitor the spread of deforestation. These maps should be updated frequently - on the order of every two years. More detailed resource maps at 1:50,000 scale and Level II or III classification are required to support development planning activities and land management decisions. Their requirement for updating will be a function of development activity or other change in the local resource base, much of which may be inferred from the regional 1:200,000 scale maps. In general, updating on a five-year basis should be adequate.

Estimates of time and costs involved to produce these resource maps on a nationwide basis in Costa Rica are presented in Tables 6-3 and 6-4. These estimates presume that these maps are prepared entirely by Costa Rican professionals in Costa Rica, with the exception of Landsat digital data processing in the United States.

Levels of effort reflected in Tables 6-1 and 6-2 are optimum and presume a trained and experienced staff with adequate facilities and materials. For reasons noted earlier in this report, the majority of the analysis and map production work on this project was completed in the United States. An operational program in Costa Rica would not function at the same levels of efficiency in its early stages. Delays in availability of field vehicles, problems due to weather, and similar factors footnoted

Alternative 1:

Mapping at Both 1:50,000 and 1:200,000 Scales

LEVEL II & III LAND COVER MAPS @ 1:50,000 Scale: (from 1:40,000 Scale CIR photography)		
135 map sheets @ $1,987	$268,245	
Other direct costs @ 30%[1]	80,474	
Indirect costs @ 100%[2]	348,719	
Contingencies @ 15%	104,562	
Subtotal:		$802,000
Time Required to Complete[3]:		3 years
LEVEL I LAND COVER MAPS @ 1:200,000 Scale: (from Landsat digital data and CIR photography)		
Nine (9) map sheets @ $13,822 per set of two	$ 62,199	
Other direct costs [1,4]	-0-	
Indirect costs @ 100%[2]	62,199	
Contingencies @ 15%	18,602	
Subtotal:		143,000
Time Required to Complete [3]: (Done in parallel with Level II/III maps)		6 months
TOTAL ESTIMATED COST:		$945,000
TOTAL TIME REQUIRED:		3 years

---

[1] Field transportation, per diem, materials, related direct costs
[2] Facilities, overhead, supervision, equipment, related indirect costs
[3] Assumes no delay due to unusual weather or cloud conditions
[4] Effectively zero costs if done in parallel with Level II/III mapping program

Table 6-3: COST AND TIME REQUIREMENTS TO PRODUCE NATIONWIDE RESOURCE MAPS IN COSTA RICA

Alternative 2:

Mapping at 1:200,000 Scale Only

LEVEL I LAND COVER MAPS @ 1:200,000 Scale (from Landsat digital data and photography)		
Nine (9) map sheets @ $13,822 per set of two	$ 62,199	
Aerial photography, interpretation and field checking to validate maps @ $1/km^2	51,000	
Other direct costs @ 30%[(1)]	33,960	
Indirect costs @ 100%[(2)]	147,159	
Contigencies @ 15%	44,682	
TOTAL ESTIMATED COST:		$339,000
TOTAL TIME REQUIRED[(3)]:		1.5 years

[(1)] Field transportation, per diem, materials, related direct costs
[(2)] Facilities, overhead, supervision, equipment, related indirect costs
[(3)] Assumes no delay due to unusual weather or cloud conditions

Table 6-4: COST AND TIME REQUIREMENTS TO PRODUCE NATIONWIDE RESOURCE MAPS IN COSTA RICA on Tables 6-1 and 6-2 will combine to initially increase both time and costs. An allowance for these factors has accordingly been included in the cost estimates presented in Tables 6-3 and 6-4, together with rough estimates of facilities, overhead, supervision, equipment, field transportation, per diem and related costs that may be incurred.

As discussed in earlier sections of this report, complete country coverage at both the noted scales and levels of detail is recommended, at least on an initial basis. This is presented as Alternative 1 in Table 6-3. A budget on the order of $945,000 would be required and the combined project could be completed within three years. Once the basic resource maps are completed, they may be updated with relative ease and little additional cost. For example, given the timely availability of satellite data, the 1:200,000 scale regional maps could be updated every year if desired.

If the 1:50,000 scale mapping project were deleted and resource maps produced only at the 1:200,000 scale, a budget on the order of $339,000 would be required over a period of one and one-half years (Alternative 2, Table 6-4). A resources mapping program of this type would not by itself satisfy current information requirements in Costa Rica and is not recommended.

If a Landsat data processing capability can be developed in Costa Rica, these costs may change substantially. The minimum cost to process a single frame of Landsat data at any of the three major commercial suppliers in the United States is from $6,000 to $10,000. This price includes production of a classified tape and land cover tabulations for one or two areas.

The Ministerio de Obras Publicas (MOP) currently maintains and operates an IBM 360 computer with associated hardware and support equipment. This system has a somewhat limited core capacity (196K). It can, however, be used to process Landsat data directly in Costa Rica by employing currently available computer programs and a limited amount of preprocessing work in the United States. The total cost to preprocess and compact the

Landsat data tapes should not exceed $2,000 per frame. Direct savings to the GOCR would then be on the order of $6,500 for every frame of satellite data that is processed, excluding costs of operating the present MOP computer. These costs should be minimal, as the present system is considerably underutilized. As an added benefit, nearly the entire resource data processing and mapping operation would then be done directly in Costa Rica by Costa Ricans. Given such a local processing capability, the cost to prepare Level I land cover maps at 1:200,000 scale for all of Costa Rica could be reduced by more than $30,000.

One particularly important factor should be noted. The 1:200,000 scale Level I resource maps are based on and require digital analysis of Landsat satellite data. At the present time, Costa Rica is outside the range of any ground-based satellite receiving station. This means that the NASA agency responsible for Landsat operations must trigger the satellite and turn on the tape recorder carried onboard as it passes over Costa Rica. Data thus collected is stored and transmitted to the next appropriate ground station as it comes in range.

This process introduces several problems. First, tape recorder "space" is limited on the Landsat system, and priorities must be assigned. The intervention of the Office of the President of the United States was required to obtain Landsat data of Costa Rica to support the Demonstration and Pilot Projects. Second, NASA has experienced significant problems with the on-board recording system, and the lifetime of the current recorders is uncertain. Third, NASA relies on weather and cloud cover forecasts provided by NOAA in deciding when to actually turn the satellite on over Costa Rica. If there is a reasonable probability of cloud cover in the target area, the satellite is not triggered and no data at all is collected. Accordingly, under the present system, data will be (and has been) collected over Costa Rica on only a fraction of the possible orbital passes.

If a Landsat ground receiving station is installed within the Central American region, Costa Rica would be assured of an opportunity to collect data on every pass of each of the Landsat satellites. With two such satellites presently in orbit, data could be collected every nine days, or 40 times a year. Between January 1974 and April 1978, it appears that only 16 frames of Landsat data were recorded over the Meseta Central area in Costa Rica, for an average of less than four frames per year. In general, this frequency of coverage is considered marginal to support a continuing nationwide program of resources assessment and environmental monitoring.

A national program of this type will require substantial commitment of GOCR funds and professional effort. Accordingly, for reasons presented here, a national resources survey program in Costa Rica, based solely on and requiring periodic Landsat data is not recommended unless a ground receiving station is positioned within the general Central American area, such that reliance on the present satellite on-board recording system is eliminated. If such a station can be so located, this project should definitely proceed as outlined.

It should be noted that only the 1:200,000 resource maps are affected by this requirement. Although Landsat data may be quite helpful in a general sense in the preparation and updating of the 1:50,000 Level II/III maps, it is not required, and that phase of the program may continue independently of any decision to install a receiving station in the Central American/Caribbean area.

7.0 RECOMMENDATIONS

The Remote Sensing Pilot Project in Costa Rica has demonstrated operational procedures for a natural resources inventory and information system that meets the current requirements of the Government of Costa Rica and can be both implemented and maintained by Costa Rican professional personnel. This system should now be implemented on a nationwide basis.

As a first step, a multi-disciplinary, multi-agency project team should be formed to complete a resources inventory of the country at mapping scales of 1:50,000 and 1:200,000, utilizing a combination of CIR photography and Landsat digital data. A single organization within the GOCR should be given clear administrative responsibility for this project.

This inventory should be combined with existing resources data in map and tabular form into a manual geo-based information system. This system should be maintained and periodically updated to monitor changes in environmental quality, the condition and the extent of the natural resources base. Combined with standard forecasting techniques, the system should assess the impact of these changes as a guide to determination of public policy and implementation of that policy. Land cover/land use can be updated for the entire country at five-year intervals using aerial photography or at two-year intervals using Landsat data.

If a Landsat ground receiving station is established in the Caribbean area in the near future, then significant benefits will accrue to Costa Rica through a marked increase in availability and volume of Landsat data. The resources information system presented in this report does not, however, require Landsat data, and should be implemented regardless of any decisions concerning Landsat ground stations.

A continuing training program should be established in Costa Rica to familiarize resources managers and data users with the techniques and application of remote sensing. A research program should similarly be initiated to further improve existing techniques of tropical resources inventory and environmental monitoring.

Specific recommendations regarding these general goals are presented in the following sections.

7.1 Management and Administration of the National Project

As a result of discussions with many Costa Rican professionals involved in natural resource surveys in Costa Rica and experience gained from the Pilot Project, the following recommendations for management and administration of the national natural resources project are offered.

7.1.1 Lead Organization

A single organization should be appointed to administer the national project. This organization should be either an established group, such as the Instituto Geografico Nacional, or a group specifically created for the task, such as a specially appointed Presidential Commission. The IGN might most appropriately be assigned this task as they are presently charged with similar mapping activities in Costa Rica. They possess equipment, facilities, and required expertise to perform the task.

7.1.2 Facilities

Facilities and equipment necessary for the national inventory should be housed and maintained within a single central agency. These facilities should be committed to the project on a first priority basis but could be made available to other user agencies.

7.1.3 Technical Liaison

Each user agency which would contribute to the national project should appoint a single permanent liaison between that agency and the National Project Manager. This individual would be responsible for coordinating all activities of his organization with the national inventory Project Manager and should possess a balance of technical and administrative skills.

7.1.4 Advisory Committee

An advisory committee should be established to recommend general and specific directions for the national project. This advisory group should include: 1) the Project Manager, 2) user agency liaison, 3) a U. S. technical advisor, and 4) one resources specialist from government or private concerns (e.g., Tropical Science Center, University of Costa Rica, etc.).

7.1.5 Personnel Assignment

To assure the continued dedication required of a sustained national effort, professionals from each participating agency should be assigned to the project either on a full-time or guaranteed part-time basis. The inventory work should be performed at the designated lead facility and in the field to the greatest extent possible. Some project tasks could be performed at the facilities of the participating agencies, as a matter of convenience.

7.1.6 Data Repository

Data collected during the course of the national project should be made available to other interested users on a non-interference basis. The project facility should be made the main repository for remote sensing and natural resource maps collected within the country.

7.1.7 Technical Consultants

The services of a U. S. consulting firm should be retained for intermittent consulting throughout the life of the project. An advisor could assist with technical problems, keep the project participants informed of new remote sensing techniques applicable to the national project and act as a liaison for required services to be performed in the United States.

7.2 Land Cover Data Collection and Processing

The data required for land cover/land use mapping are derived from both aerial photography and the Landsat satellite. The following recommendations relate to the acquisition of aerial photographic and Landsat data for the entire country.

7.2.1 Aerial Photo Missions

To obtain photographic coverage of the entire nation, the frequency of photo missions must be increased. During the dry season, the aircraft crew should be prepared to fly on a daily basis. Mission planning to avoid local cloud cover could be greatly aided by obtaining current local cloud conditions from a network of weather observers.

7.2.2 Film Processing Capability

The government should establish a film processing capability to develop both natural color and color infrared film. The processing (using Kodak E-4 chemistry) could be accomplished in the darkroom facilities at IGN. This will help Costa Rica to minimize their reliance on outside sources, while avoiding associated time delays and added expenses for processing needs.

7.2.3 Landsat Images

A standing order should be submitted to receive notification of all Landsat images collected over Costa Rica. Negative transparencies at a scale of 1:1,000,000 for all four bands should be obtained for images of sufficient quality (less than 30% cloud cover). These should be maintained in the project repository. Prints of these negatives, contact as well as

1:200,000 or greater enlargements, could be made on a routine basis by IGN using their present darkroom facilities.

7.2.4 Landsat Classification

A country-wide Landsat digital classification of land cover/land use should be performed every two years. The location of strata boundaries, registration and geometric control points, and the location of training areas should be standardized in order to provide a repeatable and accurate product. The classification must be done in the United States until such time that Costa Rica develops a processing capability.

7.2.5 In-Country Digital Classification

It is conceivable that software may be developed to perform digital classification of Landsat data using the existing, IBM 370 System computer at the MOP. This possibility should be explored in the future.

7.3 Classification and Mapping Guidelines

The following recommendations pertain to the land cover classification system (Section 4.2) and to the mapping techniques (Section 4.2.3).

7.3.1 Classification System

The classification system, as developed and described in this project, should be adopted. Level I and Level II classes should be maintained. Level III classes may be modified or extended to reflect future needs. However, once operational mapping is initiated at Level III, the classification system should become fixed in order to maintain standardization and continuity.

7.3.2 Ground Truth/Field Checks

Photo interpreters working on the project should make regular field visits to check land cover map identification points. For each 1:50,000 quad sheet, a minimum of 10 widely spaced ground sample points for each land cover class should be visited and compared with the photo interpretation sites.

7.3.3 Minimum Mapping Unit

The minimum mapping unit as proposed and used within this project should be adopted and used throughout the national inventory.

7.3.4 Overlay Materials

The use of heavy-gauge (5 mil) frosted transparent overlays is recommended for mapping purposes over the light-gauge material. Stable-base polyester films are preferred over non-stable acetate.

7.4 Ancillary Data

As applicable ancillary data are generated through sources independent of the national project, they should be incorporated into the national data base. These data should maintain reasonable standards of accuracy or reliability. Integration of new data into the data base should be greatly facilitated by the fact that the national project facility is also a national repository for resource data.

7.5 Map Production

The following recommendations pertain to preparation, format, and distribution of map products.

7.5.1 Product Scale

All output products (overlays, maps, prints, etc.) should be produced at the standard topographic map scales of 1:50,000 or 1:200,000 to increase the utility and access of resource information to prospective users. The preparation of a larger map scale, preferrably 1:25,000, may be necessary for detailed mapping and local resource investigations.

7.5.2 Scribing

All final map products should be produced by the scribing method rather than by pen and ink. This provides a clean and uniform negative suitable for mass production and is compatible with the present production system used by IGN.

7.5.3 Geographic Information System (GIS)

The proposed thematic map system, as a manual geographic information system (GIS), should be implemented. A computerized GIS may be of benefit in the future, but immediate action toward this goal would be premature. The GOCR should remain aware of advances in this field for future consideration.

7.5.4 Product Distribution and Advertisement

Copies of all output products should be distributed to participating and interested user agencies. The GOCR should investigate desirability of public distribution in a manner similar to that used to provide topographic maps. A periodic newsletter or brief announcement of program achievement and resource map availability would help to generate public support and interest in the national project.

7.6 Monitoring System

With a resources information baseline established through completion of the national project, an on-going monitoring system should be implemented to maintain a current data base. Data must be collected, analyzed, mapped, and entered into the system on a regular basis. The frequency of update will depend on many factors including data collection limitations, funding and need. The following specific recommendations apply.

7.6.1 Photo Interpreted Land Cover Mapping

Insofar as possible, land cover over the entire country should be mapped every five years from CIR aerial photography. This level of detail and frequency is necessary to monitor effectively the rapid land cover changes which are presently taking place in Costa Rica. An estimated 80% of the country can be covered by relatively cloud-free photography during a typical five-year period.

7.6.2 Landsat Land Cover Mapping

Interim land cover/land use change could be monitored by the use of Landsat. Assuming that the Landsat system can provide regular (nine-day interval) coverage on a continuing basis, relatively cloud-free data (20 to 30%) should be available for 80% of the country in a two-year period. A digital Landsat land cover classification could then be performed every two years for the entire country. This would provide continuing updates on land cover changes and would identify areas in which a critical and rapid land use change was underway. Detailed mapping from aerial photography could then be accomplished in priority areas on a more efficient and less costly basis than would otherwise be the case.

7.6.3 Urban Area Expansion

Large scale aerial photos are necessary for accurate mapping of urban area expansion and conversion of land from agricultural to urban use. These changes are occurring at such a rapid rate that frequent monitoring is necessary for land use planning purposes. As the urban areas cover a relatively small and concentrated land area, the collection of period cloud-free photography presents very few problems. The City of San Jose and surrounding urban areas in the Meseta Central should be mapped on a two-year frequency.

7.6.4 Ancillary Data

Ancillary data should be continually entered into the data base as it is generated, modified or updated. Most ancillary data (soils, geology, drainage) does not change appreciably with time and thus requires little monitoring.

7.7 Training

Development of a self-sustaining inventory work group requires periodic training of personnel. Several types of training are recommended.

7.7.1 Permanent Project Staff and User Agency Personnel

All professional staff members assigned to the national project should receive, at a minimum, an intensive training course similar to that presented as part of this project. Personnel from the user agencies should receive such training in order that a continuing and expanding capability of understanding may be developed in Costa Rica. A minimum of four persons per year should participate in training programs.

7.7.2 U. S. Post-Graduate Training

The GOCR should sponsor a minimum of two students every four years to receive post-graduage training in a U. S. university in applications of remote sensing technology to a particular natural resource discipline such as forstry, agriculture, or soils. The students should have the equivalent of a four-year college degree in his particular resource field prior to such U. S. training.

7.8 Research

The Pilot Project has identified some areas which may require further research. These activities need not be completed prior to the national project. However, on-going research activities could aid in the attainment of a meaningful and useful product, while providing incentive to graduate students and scientists to direct their energies to natural resource development.

7.8.1 Classification of Multi-Temporal Landsat Images

Study is required to investigate the possibility of employing multi-seasonal Landsat digital data in the computer mapping process. Doing so could help resolve problems encountered in the digital processing conducted for the Pilot Propject in which only single date images were used. The problem of distinguishing seasonal from perennial cover types could probably be aided by using several dates of imagery (at least two), separated by at least a few months over the growing season. The resulting map could be both more detailed and more accurate. The utility of this approach has been demonstrated in temperate climates.

7.8.2 Detailed Forest Mapping from Aerial Photography

A Level III forest classification was developed for this project. It consisted of various density/height combinations. With further refinements of this classification, these combinations may yield general predictions of timber volume, a very important parameter in forest resource valuation. Species composition is a similarly important parameter in timber valuation. Level III forest mapping for the Pilot Project could not be adequately field-checked due to limited access to forest land. Field verification is a prerequisite for development of recommendations concerning use of the forest classification. A research program should be instituted to determine and define relationships between the photo interpreted forest classes and forest measurements, including overstory stand density, height, volume, species composition, and merchantability of timber.

7.8.3 Detailed Forest Mapping from Landsat

The digital classification performed for this project defined seven different forest classes. Lacking information of the type described above (7.8.2), it was impossible to relate these classes to subgroups more detailed than "forest". However, there is reason to believe that these seven differentiations have economic significance. If the research program outlined in 7.8.2 were instituted, it would be highly desirable to include a parallel effort in this area.

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TECHNICAL ANNEX 1

CHARACTERISTICS OF THE LANDSAT SATELLITE

Technical Annex 1: Characteristics of the Landsat Satellite

On July 23, 1972, the Earth Resources Technology Satellite (called ERTS-A) was launched. It used a Nimbus weather satellite platform which was modified to carry two sensor systems and a data relay system. It was the first attempt to use a satellite as a data collection platform specifically oriented toward earth resources. On January 22, 1975, ERTS-B was launched. It was essentially a duplicate of ERTS-A and was designed to replace ERTS-A which had already exceeded its design lifetime by about 200%. In 1975, both systems were renamed Landsat.

Early in 1977, the multispectral scanner (MSS) on Landsat 1 began to fail. This followed total failure of the two wideband video recorders and exhaustion of altitude control fuel. Landsat 1 was shut down and for all practical purposes, is now "dead". On March 5, 1978, the third of the Landsat series, Landsat 3, was launched. To a large extent, it was a duplicate of the first two of the series although some changes have been made. The Return Beam Vidicon System has been altered to provide higher resolution images to aid in detailed ground mapping. The Multispectral Scanner now incorporates a fifth band in the emitted terrestrial infrared radiation region, however, this thermal band is not functional at present due to problems in the scanner itself.

All Landsat satellites make 14 orbits a day, viewing a 185 square kilometer (115 mile) wide strip of Earth. They are launched into a near-polar sun-synchronous orbit at an altitude of 900 kilometers, with the angle between the sun, center of the earth, and satellite maintained at 37.5 degrees. This ensures repeatable solar illumination conditions. In this orbit, each satellite can provide complete global coverage once every 18 days.

Every equatorial crossing occurs at approximately the same local time each day - about 9:42 AM; and this holds for all parts of the world, the spacecraft crossing any particular place about 9:00 - 10:00 AM local time each day.

At the equator, the centers of successive strips are spaced 2,800 kilometers apart, so that 14 such strips may be observed around the world every day. The orbit is adjusted so that a strip observed on one given day, in one given location, advances westward by about 170 kilometers on the next day (see Figure TA1-1). In this fashion, each spacecraft's sensors view the entire world between 82 degrees north and 82 degrees south latitude once every 18 days. Landsat 2 was launched so that it would follow Landsat 1 by nine days in orbit. Landsat 3 was lkaunched to duplicate the orbit of Landsat 1. Therefore, with the two satellites now in operation, repeat coverage of any place on the earth's surface is possible every nine days.

Limited power, data transmission, and above all, data processing capacity prevent acquisition of images over the entire world during every nine-day period. Thus, contiguous images are acquired every nine days only over the North American continent. Data from Landsat 3 was not available for the Pilot Project due to the late launch date of the satellite. Thus, the discussion which follows relates only to Landsats 1 and 2.

The Landsat payload includes these major elements (see Figure TA1-2):

1. Return Beam Vidicon (RBV) Television Cameras - These three cameras view the same 185 by 185 kilometer (115 by 115 mile) square area in three different spectral bands: green, red, and near infrared.

2. Multispectral Scanner Subsystem (MSS) - The MSS returns images in four spectral bands: green, red, and two near infrared bands. The MSS scans horizontally along the orbital track. During ground processing, frames equivalent to the 185 square kilometer scenes imaged by the RBV are constructed.

3. Data Collection System (DCS) - The DCS is a communications system, not remote sensing, experiment. It collects information from some 150 remote, unattended, instrumented ground platforms and relays the information to NASA ground stations for delivery to the users.

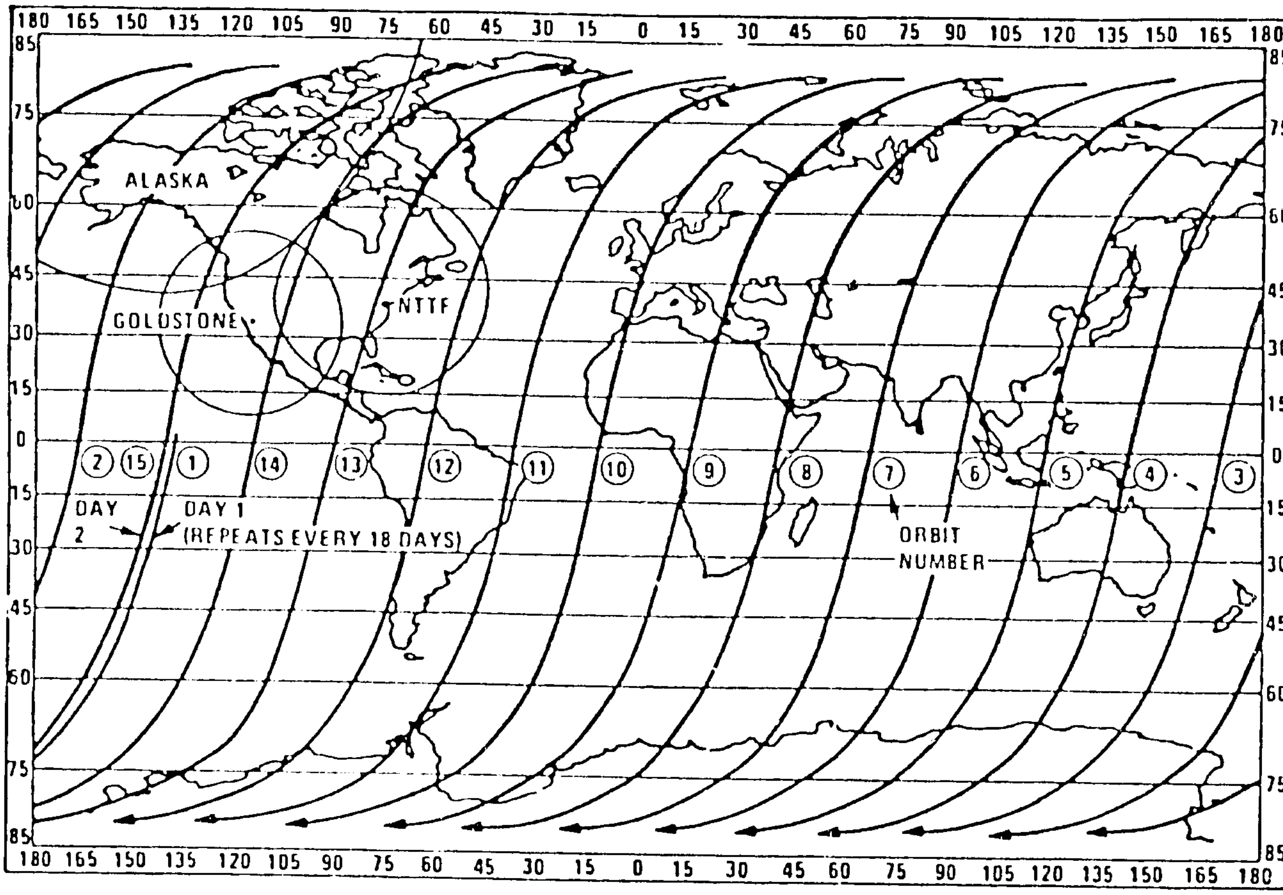


Figure TA1-1: LANDSAT ORBITAL TRACKS FOR ONE DAY OF COVERAGE
(From NASA Data Users Handbook)

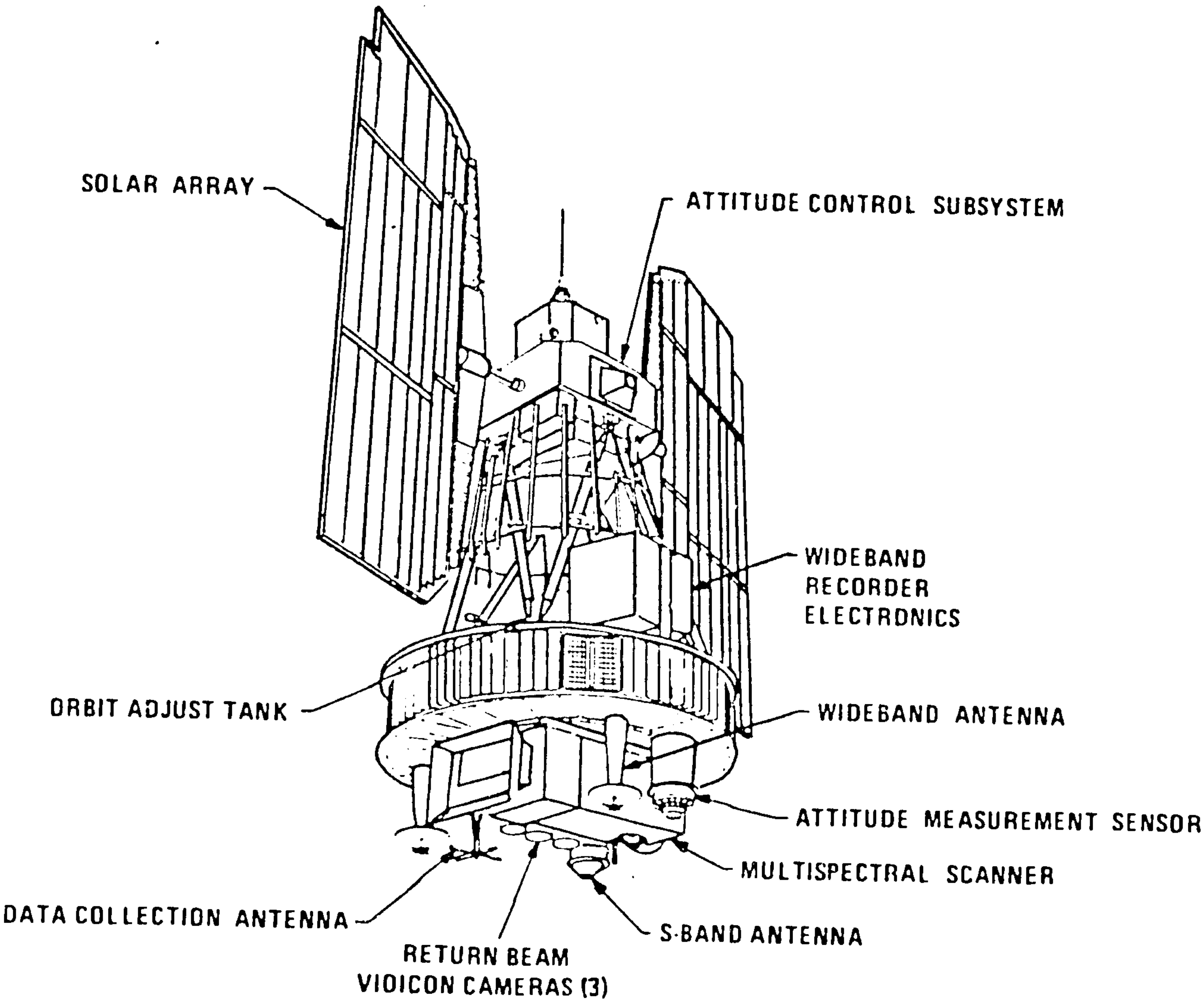


Figure TA1-2: LANDSAT SATELLITE
(From NASA Landsat Data Users Handbook)

The MSS is the only sensor system which has performed reliably and continually over the seven-year life of the systems. Thus, it has collected the bulk of the data now commonly referred to as "Landsat data". The MSS is an optical-mechanical scanner which simultaneously collects four bands of data, each representing a different spectral wavelength. The bandpasses of these bands are as follows:

NASA Code	Type of Radiation	Wavelength
Band 4	Visible Green	0.5 - 0.6 μm
Band 5	Visible Red	0.6 - 0.7 μm
Band 6	Reflected Near Infrared	0.7 - 0.8 μm
Band 7	Reflected Near Infrared	0.8 - 1.1 μm

The MSS scans six lines of data at a time. The spacecraft moves south as the six lines are scanned so the scan lines are not perpendicular to the line of flight. Approximately 3,330 samples are taken along each 185.2 kilometer raster scan line. Since the instantaneous field of view (IFOV) is 79 meters, this sampling rate implies a slight over-sampling. Thus, in order to maintain geometric fidelity, the final picture elements (pixels) are formatted to 56 by 79 meters.

The data collected by the MSS represents reflected radiation within the particular spectral bandpass. The radiation is collected by the scanner and converted to an analog voltage signal which in turn is converted to a digital-bit stream. The brightness values are represented by the digital numbers which can range from 0 to 63. This string of data is either directly telemetered to earth, if the satellite is within range of a ground receiving station, or stored on a high-density tape recorder, for later transmission if the satellite is out of range of a receiving station.

Upon reception at a ground station, the data are annotated and reformatted. Negatives are produced on an electron beam recorder. Black and white and color prints are produced for distribution. After a radiometric calibration and normalization for detector response, a computer compatible tape is produced. The data are decompressed on the tape so that bands 4, 5, and 6 have a potential range from 0 to 127 while band 7 remains at 0 to 63.

Landsat data are available to users worldwide from the Earth Resources Observation System (EROS) Data Facility in Sioux Falls, South Dakota. A Landsat Order Form can be found in Appendix (C-4).

TECHNICAL ANNEX 2

FILM CALIBRATION REPORT

Technical Annex 2: Color Infrared Film Calibration

Color infrared film has proven to be a most useful tool (Section 2.2.1.2), particularly when aerial photography is required from moderate to high altitudes. The chemistry and construction of this photographic film is, however, sufficiently different from other conventional films, therefore special handling, processing and calibration procedures are strongly recommended.

Multiple layer reversal aerial film, both color and color infrared, have a very narrow exposure latitude compared to color negative or black and white panchromatic materials. This is due primarily to the inherent higher contrast (gamma) of reversal films, which makes them quite sensitive to differences in inter-layer speed characteristics. These inter-layer differences are a function of and directly affected by changes in manufacturing, storage, and film processing.

The infrared-sensitive emulsion layer in CIR film (e.g., EK 2443) is relatively unstable and particularly affected by changes in temperature, both before and after exposure. As temperature increases above zero degrees Celsius, the sensitivity of this emulsion layer decays rapidly with time. This is a problem of major concern, as it is this infrared layer that permits identification and discrimination of many important differences in vegetation that may otherwise be invisible to the human eye. Adverse storage conditions will cause a change in color balance as well as in overall film speed and sensitivity. A loss of infrared sensitivity and color balance shift toward cyan typifies film that has been stored in less-than-adequate conditions.

This problem is compounded by difficulties experienced by the manufacturer in production quality control. In many cases, the sensitivity of the infrared emulsion layer has been found to vary significantly between production runs. Similar problems and consequences can arise during laboratory processing of the exposed film. Since vegetation that has been stressed by disease, insect infestation, inadequate irrigation or otherwise adversely affected by man's activities also exhibits a reflectance shift toward cyan, an obvious and often serious confusion in analysis and interpretation can result. A "blue" color in the final photography may be a result of poor storage and handling, poor processing, a "normal" difference between production runs, or indicative of a major resource problem that requires prompt attention.

A properly-designed film calibration program can eliminate much of this confusion. Immediately upon receipt of the film from the manufacturer, color sensi-wedges are exposed in a small section. A portion of this exposed film is then cut off, processed, and D-Log-E curves plotted for each emulsion layer. These curves and the respective rolls of film are uniquely coded and identified. If color compensating filters are required to obtain a desired "standard" overall color balance between production run films they are identified at this time. After the aerial photography has been acquired and processed, a second set of D-Log-E curves is prepared from the sensi-wedges remaining on the film. Differences between these curves and the original ones are directly traceable to problems of handling and processing. In this manner, the analyst and photo interpreter may be assured that differences in the ground scene are "real" and not a function of errors in film handling, processing, exposure, or differences in film chemistry.

Such a calibration and quality control program assumes increased importance in light of recent action by the Environmental Protection Agency in the United States. Film processing chemicals used in the EA-4 and EA-5 process (for color infrared film) have been found to pose a significant environmental hazard. Although the matter has yet to be resolved, the prevailing opinion among scientists in this field is that the processing chemistry will be changed in the near future. This will most likely mean a concurrent change in emulsion sensitivity. If a film calibration program is in place in Costa Rica when this change occurs, then color balances can easily be adjusted to the "standard" developed for the program. Without such a standard, there will be nothing to adjust to, and the utility of previous photography for comparative resources analysis purposes will be sharply reduced.

This procedure was followed o· the pilot program and calibration curves were plotted for ·ıll CIR film used. "Before" and "after" curves for two typical rolls of EK 2443 are shown in Figures TA2-1 through TA2-4. The area of primary interest in these curves centers about the 1.0 density level.

Figures TA2-1 and TA2-3 show the relative sensitivities of the three dye layers of rolls 1 and 2 respectively, as recorded on January 10, 1978. These films were subsequently shipped to Costa Rica, exposed on the pilot project, and returned to the U. S. for processing. They were processed on February 27, 1978, at which time the curves shown in Figures TA2-2 and TA2-4 were plotted.

Comparison of Figure TA2-1 with Figure TA2-2, and Figure TA2-3 with Figure TA2-4, shows that this film was properly handled in the field. There has been a slight loss of speed, averaging about 0.25 stop. This is within normal limits and both films are affected in approximately equal amounts. There has been an apparent 0.5 stop change in blue density in both films, resulting in a slightly yellow image. This is a function of processing, and not storage or handling in the field.

In summary, the calibration procedure has developed a data set that may be used as a reference standard for continued programs or a project of national scope. It has demonstrated that the storage and handling procedures used by the IGN are both adequate and appropriate to the task. This calibration procedure should be included in any future projects involving CIR film for two principal reasons:

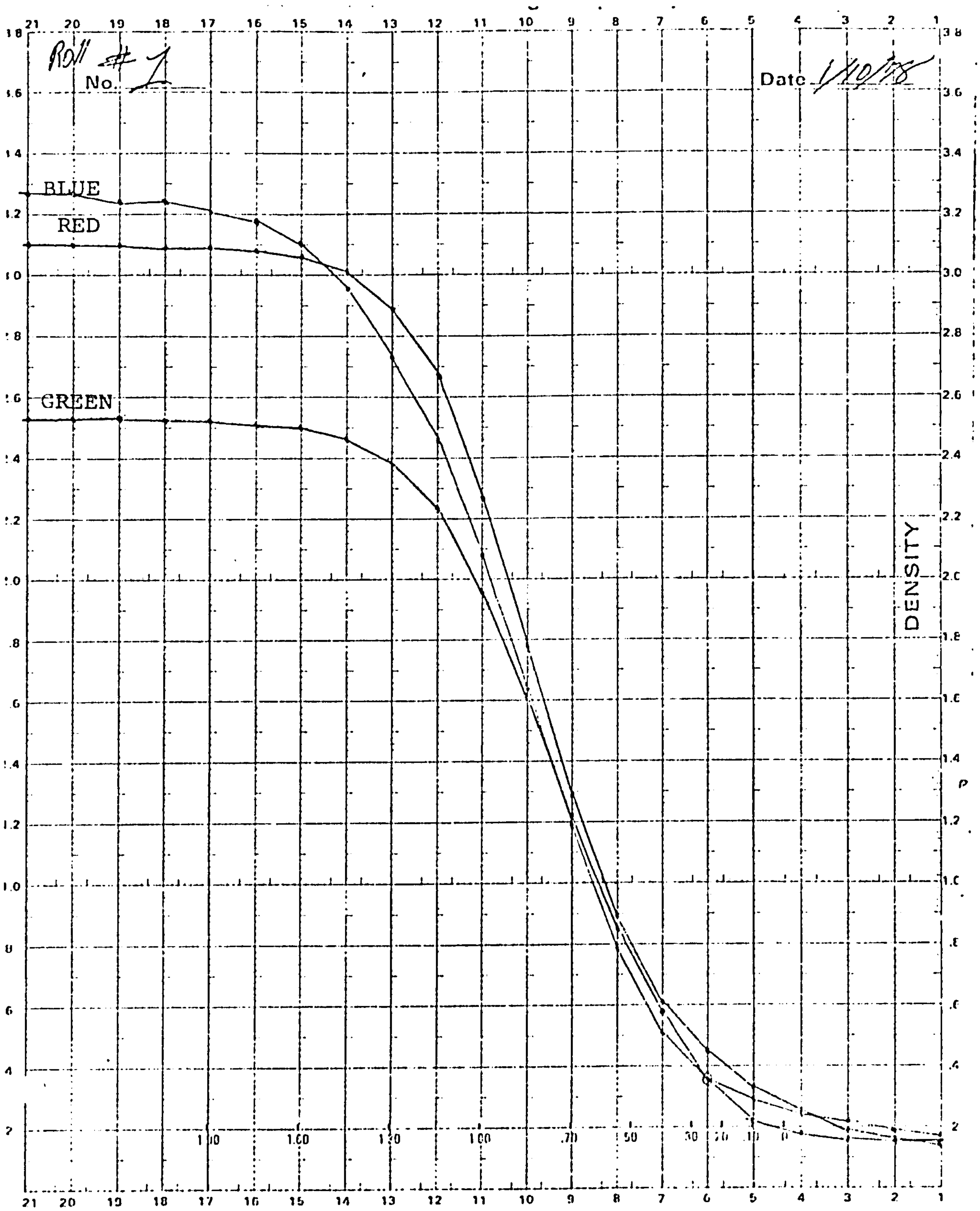


Figure TA2-1: FILM RESPONSE CURVE; ROLL 1, 1/10/78

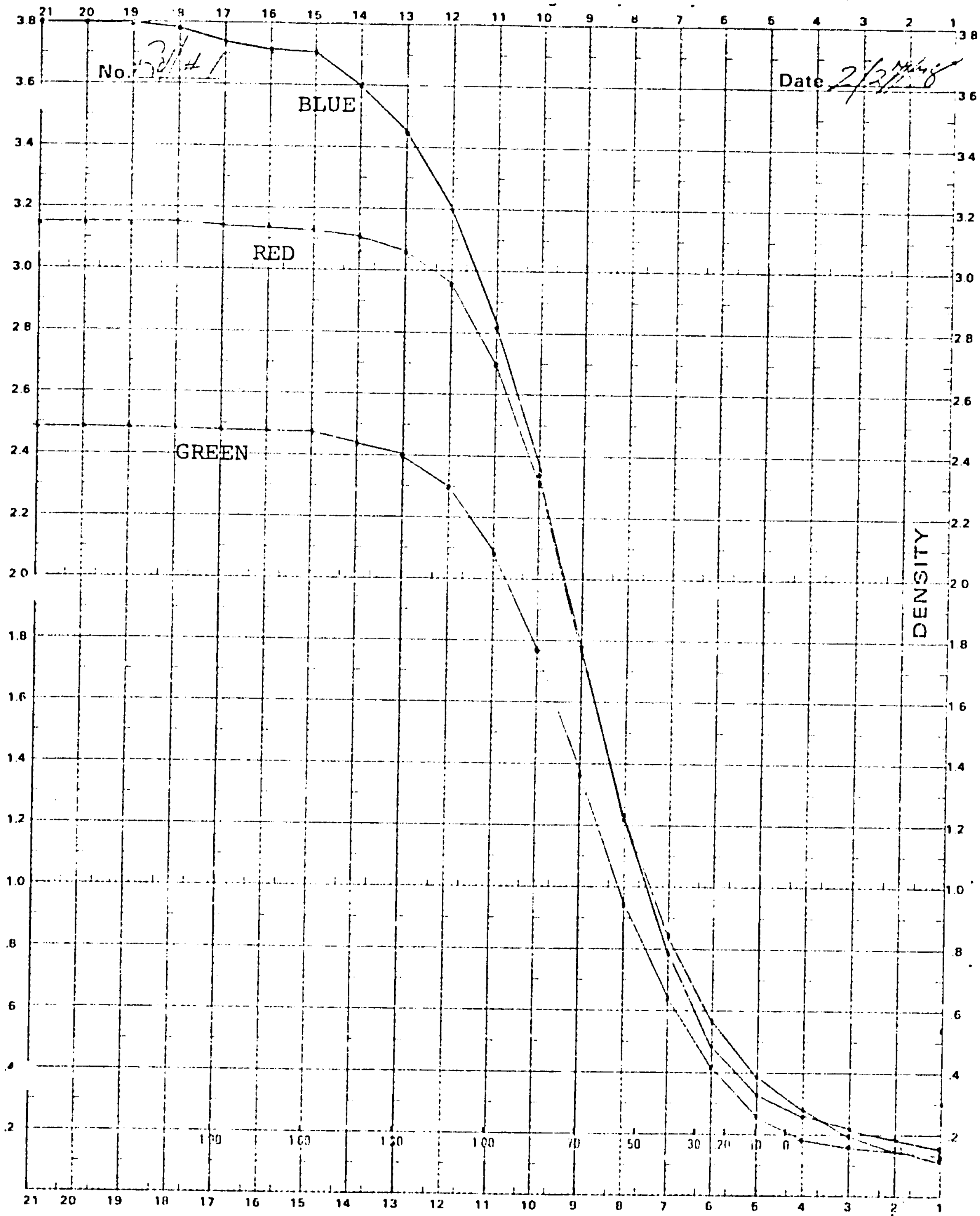


Figure TA2-2: FILM RESPONSE CURVE; ROLL 1, 2/27/78

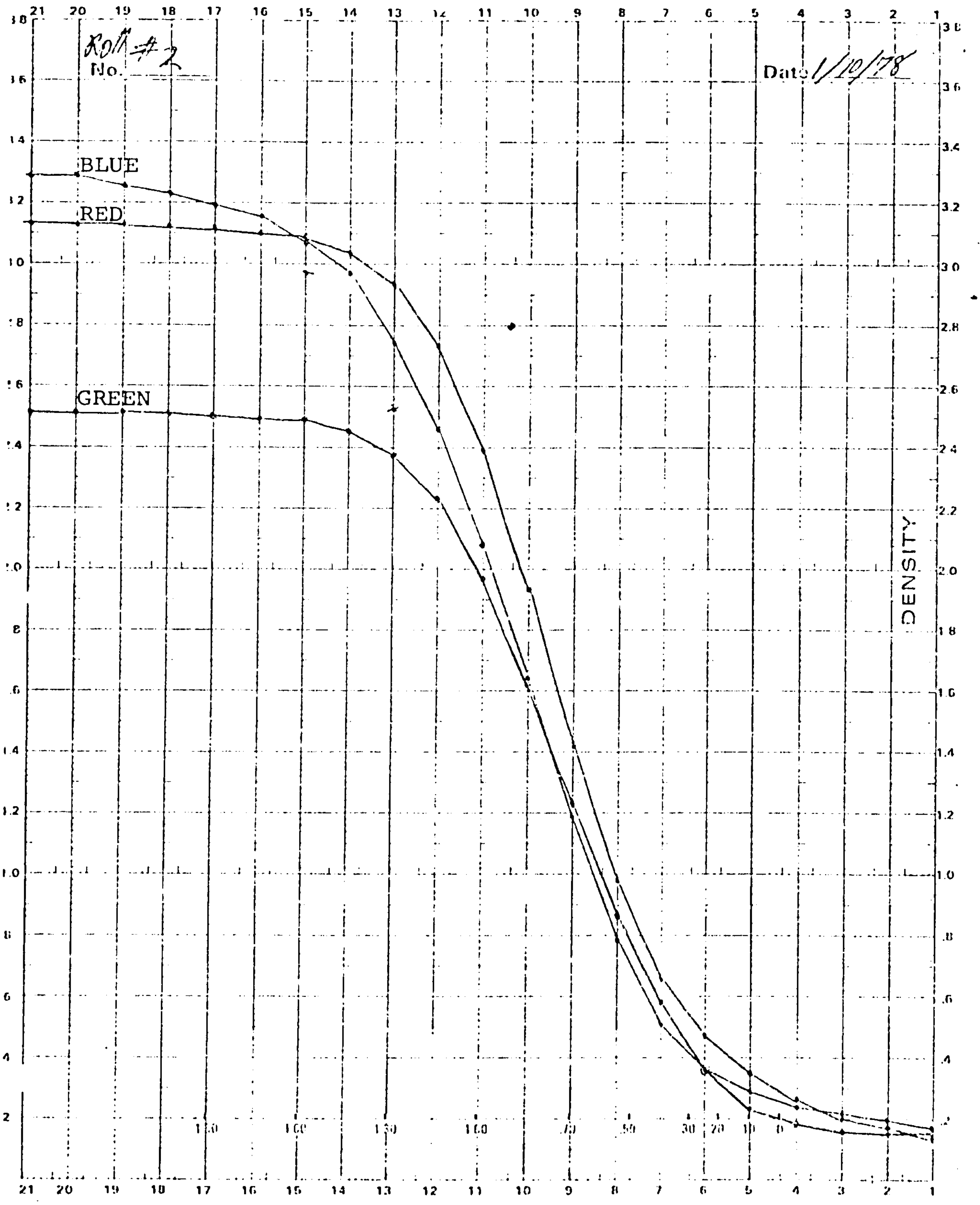


Figure TA2-3: FILM RESPONSE CURVE; ROLL 2, 1/10/78

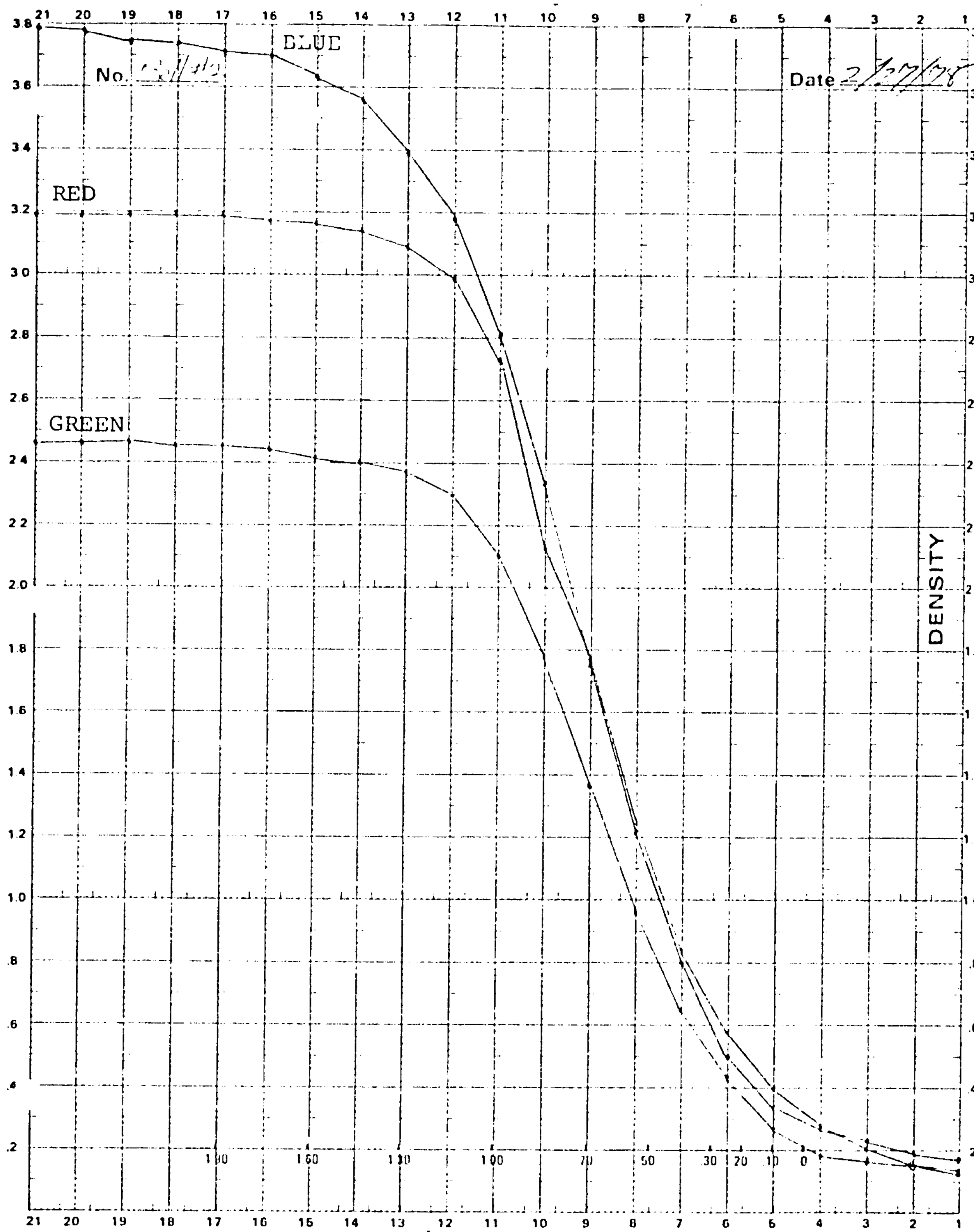


Figure TA2-4: FILM RESPONSE CURVE; ROLL 2, 2/27/78

1. to identify films whose relative sensitivities differ substantially from the "standard",

2. to identify films damaged by inadvertent storage or handling error.

In the case of "damaged" film, the data may still be of substantial value, but interpreters should be made aware that the obvious changes in color or color balance are not a function of "real" changed reflectance values in the ground scene. In the case of film sensitivity differences, where the blue and green dye layers are overly sensitive, color correction (cc) filters may be employed during flight operations to shift the balance back to the accepted "standard".

This will not be possible when the red (infrared sensitive) dye layer is much more sensitive than normal. When this occurs, the film rolls so identified should be flagged and set aside. While these rolls would not be suitable for use over heavily vegetated areas where infrared reflectance is uniformly high, they would be particularly useful for areas with relatively sparse vegetation. As an example, CIR film with unusually high infrared sensitivity could be used to very good purpose over portions of the Guanacaste Peninsula.

TECHNICAL ANNEX 3

URBAN GROWTH PROJECTIONS

Technical Annex 3: Urban Growth Projections

Matrix methods were used for both the description and projection of urbanization in the Meseta Central/San Jose metropolitan area. This is a modeling technique, and it must be emphasized that models are useful for understanding reality, but they should not be confused with the reality itself. The use of models identifies the dependent factors and suggests what the independent factors will be.

Stochastic (or probabilistic) models are those which have probability components built in. The stochastic model allows for the probability that the variables can take on various values. When using a stochastic model, it must be recognized that some of the model's components are random variables rather than average values.

By using the urbanized area boundaries shown on Figure 5-9, sampling areas for data gathering were defined. The 1945 - 1965 sampling area includes all land within the 1945 urbanized area boundary in addition to the fringe area extending to the 1965 boundary. Likewise, the 1965-1977 sample area includes all land within the 1965 boundaries in addition to the fringe extending to the 1977 boundary. Sample points were randomly determined by using a programmable calculator to generate pairs of random number coordinates corresponding to the X and Y axis and then locating these points on the map with an electronic digitizer.

All sample points were located on a pair of images--either 1945 and 1965 or 1965 and 1977--and the generalized stage of land use was noted for each date. It was recognized that virtually all changes from rural uses to urban uses could be incorporated into the following general stages:

1. land remaining in viable agricultural usage,
2. abandoned agricultural land,

3. land showing visible evidence of rural to urban conversion,

4. land in urban use.

The stages for each pair of dates are reported as an individual transition (t_{ij}) in a "tally" matrix (T) in which the stages for the initial date are listed along the vertical axis and the stages for the latter date are on the horizontal axis as illustrated in Figure TA3-1. Represented in conventional matrix format, but corresponding with the row and column labels in Figure TA3-1, the 1945 - 1965 upper triangular tally matrix takes the form.

$$\underline{T}_{45-65} = \begin{bmatrix} 07 & 04 & 17 & 16 \\ 00 & 03 & 06 & 06 \\ 00 & 00 & .1^{*} & 13 \\ 00 & 00 & 00 & 28 \end{bmatrix} \begin{matrix} \Sigma t_{45} \\ 45 \\ 15 \\ 13 \\ 28 \end{matrix}$$

$$\Sigma t_{65} \quad 07 \quad 08 \quad 23 \quad 63 \quad \boxed{101}$$

and for the 1965 - 1977 period:

$$\underline{T}_{65-77} = \begin{bmatrix} 06 & 06 & 13 & 17 \\ 00 & 04 & 03 & 07 \\ 00 & 00 & 05 & 21 \\ 00 & 00 & 00 & 33 \end{bmatrix} \begin{matrix} \Sigma t_{65} \\ 42 \\ 14 \\ 26 \\ 33 \end{matrix}$$

$$\Sigma t_{77} \quad 06 \quad 10 \quad 21 \quad 78 \quad \boxed{115}$$

---

* Although a few examples of land in transition in 1945 were still in transition in 1965, their size and number were too small to be identified by the sample. Leaving that element as zero would have resulted in a singular matrix for which no inverse exists. To allow for the inversion procedure in the growth projection a small number, 0.1, was used in place of zero.

Subsequent Date

tial
te

	1 Viable Agriculture	2 Abandoned Agriculture	3 Transition	4 Built-up	Sums For Initial Date
1 Viable Agriculture	element 11	12	13	14	---
2 Abandoned Agriculture	21	22	23	24	---
3 Transition	31	32	33	34	---
4 Built-up	41	42	43	44	---
Sums For Subsequent Date	---	---	---	---	Total

Figure TA3-1: MATRIX FORMAT

These matrices primarily reveal a general conversion of rural to urban land uses. For example, sums for the 1945 - 1965 period show that of 45 sample points categorized as "viable agriculture" in 1945, only seven of these same points remained in that category in 1965--20 years later. A similar rural to urban trend was also identified in the shorter 1965 - 1977 period.

By transforming the raw score transitions (t_{ij}) in the tally matrix (T) into proportional values representing the proportional extent of each conversion element (c_{ij}) where

$$c_{ij} = \frac{t_{ij}}{\Sigma t_{ij}}$$

a conversion matrix (C) can be derived and applied to both descriptive and predictive analysis of growth. Assuming that the sampling technique was truly random, each proportion may be used to calculate the respective area attributed to each conversion category given the total area of the sampling area. The conversion matrices corresponding to the 1945 - 1965 and the 1965 - 1977 tally matrices are:

$$\underline{C}_{45-65} = \begin{bmatrix} .0693 & .0495 & .1683 & .1584 \\ .0000 & .0297 & .0594 & .0594 \\ .0000 & .0000 & .0010 & .1277 \\ .0000 & .0000 & .0000 & .2772 \end{bmatrix} \quad \begin{matrix} \Sigma c_{45} \\ .4455 \\ .1485 \\ .1287 \\ .2772 \end{matrix}$$

$$\Sigma c_{65} \quad .0693 \quad .0792 \quad .2287 \quad .6227 \quad 1.0000$$

$$\underline{C}_{65-77} = \begin{bmatrix} .0522 & .0522 & .1130 & .1478 \\ .0000 & .0348 & .0261 & .0609 \\ .0000 & .0000 & .0435 & .1826 \\ .0000 & .0000 & .0000 & .2870 \end{bmatrix} \quad \begin{matrix} \Sigma c_{65} \\ .3652 \\ .1218 \\ .2261 \\ .2870 \end{matrix}$$

$$\Sigma c_{77} \quad .0522 \quad .0870 \quad .1826 \quad .6783 \quad | \; 1.0000$$

From the marginal sums associated with the conversion matrices, the absolute areal expansion or contraction of the stages for each period's sample region can be determined by multiplying the marginal sum proportions by the appropriate area: the 1945 - 1965 sample region consists of 3119 hectares; the 1965 - 1977 sample region consists of 7771 hectares.

The matrices can be interpreted by using the rule of reading across the rows to determine the fate of the initial date's four stages and reading down the columns to reveal the composition of the final date's four stages. The marginal sums associated with the 1945 - 1965 conversion matrix indicate that land in transition accounted for almost 13% of all land within the sampling region for the 1945 date. By 1965, essentially all of this land was fully converted to built-up urban uses. In addition, a total of almost 23% of this region had converted from the viable and abandoned agriculture categories and was now in the transition stage. To find this much land in the transition stage suggests that a remarkable period of urban development was in progress in 1965. Furthermore, the almost complete conversion of the 1945 land in transition to urban uses, suggests that the conversion process took substantially less than 20 years.

Elements of the conversion matrix for 1965 - 1977 indicate that the period of intensive development actually affected a much larger area than that within the 1945 - 1965 region. Note especially that the 23% figure for the 1965 date in the 1945 -

1965 period represents approximately 713 hectares of land in the transition stage. In the much larger region covered by the 1965 - 1977 matrix, 23% is also seen to be the 1965 transition stage figure. It, however, represents 1757 hectares. Although the amount of land in the transition stage in 1977 is seen to have decreased to 18%--suggesting that the intensity of develoment has leveled off due to the decline in non-urban land available for urban uses--the fact that 4% or about 338 hectares were found to remain in transition for the entire 12-year period suggests that real estate speculation occurred.

In this area, the expansion of urban built-up land indicates a contraction of agricultural land. This expansion of urban built-up land in the San Jose area is readily evidenced by the conversion matrices for either period of growth. Both periods show that initially the proportions for land in the urban built-up stage were almost equal (about 28%). At the end of each period, the proportions were also remarkably similar (62% and 68%). The increase from 28% to 62% which took place in the 20 year period from 1945 - 1965 amounted to 1078 hectares. The increase from 28% to 68% which took place during the 12 year period from 1965 - 1977 amounted to 3041 hectares principally because of the much larger sample area.

Markov chain analysis, a stochastic technique in which the projection of future development is only dependent on the present state, provides a portion of the framework used for the projection of growth in the San Jose area. One concept of Markov chain analysis involves the derivation of probabilities for the occurrence of conversion from one state to another. In our example, this corresponds to the probability of an initial land-use stage converting to any other state within the given time period. These probabilities form the transition probability matrix (P) which can be derived from the conversion matrix by the following equation:

$$\underline{P} = \sum_{1}^{i} \left(\frac{c_{ij}}{\Sigma \underline{C}_i} \right)$$

The transition probability matrix for the 1965 - 1977 period is

$$\underline{P}_{65-77} = \begin{bmatrix} .1429 & .1429 & .3094 & .4047 \\ .0000 & .2857 & .2143 & .5000 \\ .0000 & .0000 & .1924 & .8076 \\ .0000 & .0000 & .0000 & 1.000 \end{bmatrix}$$

The transition probability matrix can be perceived as consisting of rows of transition probabilities (probability vectors) whose individual sums equal one. The second row in the preceding matrix, shows a .5 probability of a randomly selected abandoned agricultural land site being converted to a built-up stage within a 12 year period.

Markov chains can be used to create an uncontrolled growth model based on the transition probability matrix. On the assumption that the conversion characteristics observed in the 1965 - 1977 period continue unhampered, projections of future states can be derived by calculating exponential powers of the transition probability matrix. By squaring the 12 year transition probability matrix, a 24 year transition probability matrix is created; a 36 year matrix is created by raising the 12 yer matrix to the third power; a 48 year matrix by using the fourth power and so on. Of course, the projection of past trends for such long times is not a statistically proper technique. Any of a number of factors could alter the pattern of growth; in this particular example, the amount of land simply unsuitable for built-up land uses would probably inhibit urbanization. Evidence does show, however, that the processes of land-use conversion are first-order Markov processes (20). Therefore, if only short-range projections into the immediate future are made, they would be credible.

Data for single year time intervals could be used in growth projections, but there are two disadvantages: 1) the collection of data on an annual basis is costly; and 2) short-term trends may significantly influence the projection. Therefore, the temporal deconsolidation of a long growth period into yearly intervals, is a desirable alternative to annual data collection (21). In particular, deconsolidation of the 12 year 1965 - 1977 conversion matrix into an annual conversion matrix will allow the projection of growth for single-year increments beyond the 1977 date. The deconsolidated conversion matrix is found by the following formula:

$$\underline{C}^{1/n} = \underline{F}\,\underline{\Lambda}^{1/n}\,\underline{F}^{-1}$$

where $\underline{F}$ is the matrix of eigenvectors ($\underline{f}'$) calculated for the matrix $\underline{C}_{65\ 77}$

$\underline{\Lambda}^{1/n}$ is the nth root of the diagonal matrix of eigenvalues (λ_{ii}) calculated for the matrix $\underline{C}_{65-77}$

$\underline{F}^{-1}$ is the inverse of $\underline{F}$

n is the number of intervals in the original matrix

The actual computation of eigenvalues, eigenvectors, and matrix inverses, in addition to matrix multiplication, is generally handled by computers. By applying the above operation to the 1965 - 1977 conversion matrix we find

$$(\underline{C}_{65-77})^{1/12} = \begin{bmatrix} .7819 & .0779 & .1315 & .0031 \\ .0000 & .7559 & .0426 & .0145 \\ .0000 & .0000 & .7700 & .0984 \\ .0000 & .0000 & .0000 & .9012 \end{bmatrix}$$

The deconsolidated conversion matrix has few shared characteristics with the previously discussed conversion matrices and is not interpretable as such. Its sole function is as a growth multiplier which can be used in succession on the conversion matrices it produces until the desired data is reached. In the problem at hand, one iteration yields a relative estimate of the 1965 - 1978 conversion matrix that can be multiplied by a scaler value which is the reciprocal of the sum of the elements to arrive at the actual proportions. The second iteration--performed on the corrected product of the first yields a 1965 - 1979 conversion matrix; a third iteration yields a 1965 - 1980 matrix and so on. The uncorrected conversion matrix projection for the 1965 - 1980 period is:

$$.8937(\underline{C}_{65-80}) = \begin{bmatrix} .0311 & .0371 & .0858 & .1705 \\ .0000 & .0189 & .0182 & .0645 \\ .0000 & .0000 & .0250 & .1791 \\ .0000 & .0000 & .0000 & .2638 \end{bmatrix} \begin{matrix} .3244 \\ .1015 \\ .2040 \\ .2638 \end{matrix}$$

$$\begin{matrix} .0311 & .0560 & .1289 & .6778 \end{matrix} \quad .8937$$

and by multiplying each element by the reciprocal of .8937 we find the corrected version

$$\underline{C}_{65-80} = \begin{bmatrix} .0348 & .0415 & .0960 & .1908 \\ .0000 & .0211 & .0203 & .0721 \\ .0000 & .0000 & .0279 & .2004 \\ .0000 & .0000 & .0000 & .2951 \end{bmatrix} \begin{matrix} .3630 \\ .1136 \\ .2283 \\ .2951 \end{matrix}$$

$$\begin{matrix} .0348 & .0626 & .1442 & .7584 \end{matrix} \quad 1.0000$$

This provides a credible model for uncontrolled growth to 1980 within the 7771 hectare 1965- 1977 boundary. This model estimates that 26% of the entire area (2020 hectares) will convert from viable and abandoned agricultural land to built-up land by 1980. Furthermore, by including <u>all</u> land-use stages (including transitional) that converted to built-up areas, about 46%, or 3575 hectares, will convert by 1980. It has already been noted that 3041 hectares converted during the 1965 - 1977 period, thus the difference--534 hectares--is projected to be converted in the three-year period 1977 - 1980.

APPENDIX A-1

LAND COVER CLASSIFICATION LEVELS

Level of Classification					
I		II		III	IV
1	Urban	11			
2	Agriculture	21			
3	Rangeland	31	Herbaceous Rangeland		
		32	Pasture		
		33	Brushland		
4	Forest Land	41	Deciduous	Forest Associations	Stand, Height, Density, Age, Volume, Etc.
		42	Evergreen		
		43	Semi-Deciduous		
		44	Mixed		
5	Water				
6	Wetland				
7	Bare Ground				

(Modified from Anderson)

1/ Forest management (as distinct from forest assessment) typically requires information at this level of detail

This table is from the Demonstration Project Report, Forest Sector. The level of detail shown in 4 Forest is implied for the other cover classes.

APPENDIX A-2

SCALE EVALUATION

Flying Height/Scale	Evaluation of Resulting Data
Low Altitude/ Large Scale[1]/	Excellent ground resolution, able to easily identify individual tree crowns, measure tree heights, make some species identification. Levels I, II, III
Medium Altitude/ Medium Scale[2]/	Good ground resolution, forest type or associations mapping is possible, if crown configurations and color are distinct, typing between Levels I and II
High Altitude/ Small Scale[3]/	Not evaluated due to excessive flying height requirements

[1]/ Typically, altitudes of 2,500 feet to 10,000 feet above mean terrain, with photographic scales of 1:5,000 to 1:20,000

[2]/ Typically 10,000 to 30,000 feet, scales of 1:20,000 to 1:60,000

[3]/ Typically altitudes in excess of 30,000 feet, scales smaller than 1:60,000

This table is from the Demonstration Project Report, Forest Sector. Although the level of detail is described in terms of forestry data, a similar level of detail may be inferred for other land cover types and uses.

APPENDIX A-3

APPLICABILITY OF REMOTE SENSING SYSTEMS TO LAND COVER CLASSIFICATION LEVELS

Level	Satellite Imagery	Medium Scale Aerial Photography	Large Scale Aerial Photography
Level I	High applicability; can delineate large land cover areas for survey purposes; can provide system update and monitoring information.	Excellent resolution but amount of data obtained far exceeds this level; costs of data gathering too high.	
Level II	Can discriminate within some classes fairly accurately; small areas (less than three hectares) are difficult to delineate due to resolution limits.	Well suited for this level; within resolution limits of the system; costs of data gathering comparable to information gained.	Excellent resolution but amount of data obtained far exceeds this level; costs of data gathering too high.
Level III	Rarely useful at this level due to both spectral and spatial resolution limits.	Well suited for this level; well within resolution limits of the system; costs of data gathering comparable to information gained.	Well suited for this level; within resolution limits of the system; costs of data gathering high compared to information gained.
Level IV		Rarely useful at this level due to spatial resolution and parallex limits.	Well suited; can be used for height, crown density, and some other volume-related measurements.

This table is taken from the Demonstration Project Report, Forest Sector.

APPENDIX B-1

NSTL TRAINING CURRICULUM

GENERAL REMOTE SENSING WORKSHOP

May 30-June 2, 1978

Held at the
National Space Technology Laboratories

U. S. Geological Survey
EROS Applications Assistance Facility

FORESTRY REMOTE SENSING WORKSHOP

May 30, 1978 (Tuesday) 8:30 a.m.

Welcome - Frank Beatty

Workshop Purpose and Procedures - Pat O'Neil

Introduction to Remote Sensing

I. Introduction to Remote Sensing - An Overview via Slides - B. Congdon
   - Movie: "EROS...Response to a Changing World" (USGS/EROS)
   - Movie: "ERTS" (NASA)
   o Tools of the Trade - B. Congdon

   Lunch (11:15 - 12:15)

   o Tour of EROS Applications Assistance Facility - B. Congdon & Staff
   - Remote Sensing Library - F. Beatty
   - Imagery Availability - B. Congdon
   - Users Assistance Facility - B. Congdon
   - Imagery Access Procedures - P. O'Neil/H. Svehlak (NCIC
   o Equipment Handout

   Break

Basic Principles

II. Imagery Principles
   o Introduction to Aerial Photography - F. Beatty
   - Aerial Cameras
   - Platforms
   - Data Formats
   - Electromagnetic Spectrum
   - Film Filters
   - Resolution
   - Movie: "Whole Earth's Invisible Colors"

May 31, 1978 (Wednesday) 8:30 a.m.

III. Basic Fundamentals of Imagery

   o Philosophy of Photo Interpretation - F. Beatty
   - General Overview
   - Reference Sources and Manuals

- Techniques and Procedures
- Ground Truth Practices

Break

o Stereoscopy - F. Beatty/P. O'Neil
- Stereo Demonstration
- Stereo Test
- Preparation of Stereograms
- Color Blindness Test

Lunch (11:15 - 12:15)

o Photographic Mensuration - F. Beatty/P. O'Neil
- Scale Determination - F. Beatty
- Horizontal Measurements - F. Beatty
- Area Measurement - F. Beatty
- Vertical Measurements - P O'Neil

Break

- Movie: "Mapping by Photogrammetric Methods" (USGS)

Forestry and Vegetation Applications

. Forest and Vegetation Interpretation - P. O'Neil
o Procedures and Aids in Interpretation

e 1, 1978 (Thursday) 8:30 a.m.

- Interpretation and Delineation-Exercise #1, Aircraft, Color Infrared (1:40,000, 2X Enlargement, Pine Upland)
- Interpretation and Delineation-Exercise #2, Aircraft, Color Infrated to Landsat MSS (River Basin)

Break

- Interpretation and Delineation-Exercise #3, Aircraft, Color Infrared (1:120,000, 4X Enlargement, Coastal Marsh)

Lunch (11:30 - 12:30)

V. Forest Vigor - P. O'Neil
o Forest Infestations and Stress
- Interpretation Exercise
- Movie: "A Certain Distance" (USFS)

VI. Land Use Interpretation
- o Land Use - An Overview - F. Beatty
  - Land Cover
  - Classification Systems (Professional Paper 964)
- o Basic Land Use Interpretation Exercise - F. Beatty
  - Critique and Field Check Procedures

Break

- o Land Use Techniques with Small Scale Imagery - F. Beatty
  - Mississippi State-Wide Land Use Mapping Program
- o High Altitude Land Use Interpretation Exercise

June 2, 1978 (Friday) 8:30-11:30 a.m.

VII. Basic Principles of the Multispectral Scanner System
- o Multispectral Scanners - F. Beatty
  - Electromagnetic Spectrum
  - Physical Laws
  - Atmospheric Windows
  - Object Signatures
  - Scanner Design and Operation Parameters
- o Landsat Signature Exercise - F. Beatty

Break

VIII. Mission Planning - F. Beatty
- Delineation of Interest Areas
- Scale Determination (Min. Object Size)
- Film/Filter Selection Factors
- Number of Photos
- Flight Line Layout
- Contract Specifications (ASP and Forest Service)
- Coverage Plots and Photo Indices

IX. Workshop Critique and Conclusion

WORKSHOP CONCLUDES AT 11:30 A.M.

APPENDIX B-2

RDA/SJSU TRAINING CURRICULUM

Monday 12 June	Tuesday 13 June	Wednesday 14 June	Thursday 15 June	Friday 16 June
Data Enhancement (Schwarz/Campbell) • Introduction • Analog and Optical • Digital	Forestry Lab (Basic Non-Digital) (Cannon)	Other Resource Applications (Campbell) • Geomorphology • Geology • Hydrology • Environmental • Soils (Cannon)	Forestry Applications II: Digital (Cannon) Urban Agricultural and Land-Use Applications II: Digital (Ellefsen)	Forestry Applications III: Digital (Cannon) Urban Agricultural and Land Use III (Ellefsen)
Coyote Test Site (Sader/Cannon/Campbell) San Jose Urban (Ellefsen/Schwarz) Field Trips	Urban Lab (Basic Non-Digital) (Ellefsen)	I^{2}S Field Trip Selection of Training Areas on CR Landsat	ESL Field Trip	Summary Session

Monday 19 June	Tuesday 20 June	Wednesday 21 June	Thursday 22 June	Friday 23 June
Forestry/Agricultural Lab Costa Rica (Mapping from Airphotos) (Sader/Cannon)	Map Compilation Techniques (Peruzzi)	Map Compilation Techniques (Peruzzi)	Geo-Based Information Systems (Sader)	Economics of Remote Sensing (Craib) Resource Survey Planning (Cannon)
Land-Use Urban Lab Costa Rica (Mapping from Airphotos) (Schwarz/Ellefsen)	Forestry/Urban Lab Conclusion (Compare with ESL Classification)	USGS #2 (Peruzzi) • Cartography • Compilation and Equity • Reproduction • Land Use Program	Case Study • Geostatistical Study (Glenn Kendall) Conclude Costa Rica • Field Planning • Labs • Ground Truth Areas	Graduation

Monday 5 June	Tuesday 6 June	Wednesday 7 June	Thursday 8 June	Friday 9 June

Introduction
 	
History of Remote Sensing
(Craib)
 	
Review of Theory
(Schwarz)
 	
Hardware
(Schwarz)
 	
• Photographic Process
• Photographic Systems
• Film-Filter
• Resolution
• Stereo
• Multispectral
	Non-Photographic Systems
	(Schwarz)
	
	Imaging
	(Schwarz/Campbell)
	
	• Scanners
	• Vidicons
	• Radar
	• Passive Microwave
	
	Non-Imaging
	(Campbell)
	
	• Gravity
	• Aeromagnetics
	• Radiometric
	
	Sensor Platforms
	(Campbell)
	
	• A/C
		Spacecraft Platforms
		(Ellefsen/Schwarz)
		
		• Landsat
		  • System Desription
		  • Operation
		  • Output Products
		
		Multi-stage Sampling
		(Sader)
		
		Multi-Date;
		Change Detection
		(Sader)
			NASA - AMES
			Field Trip
			
			• U-2
			• Camera Systems
			• Computer Search & Retrieval
				Classification
				Rationale
				
				• General
				(Schwarz)
				• Forestry
				(Cannon)
				
				Forestry Application
				I: Non-Digital
				(Cannon)
				
				Forestry Ground
				Truth
				(Cannon)

Airphoto A/C USGS Tour Photogrammetric Operations	Lab (Basic P/I and Mensuration) (Schwarz)	Mission Planning (Cannon) Mission Planning Lab (Cannon)	Conference of Latin American Geographers	Land-Use, Agriculture and Urban Applications I: Non-Digital (Ellefsen) Classification Rationale (Ellefsen) Urban Ground Truth (Ellefsen)

APPENDIX C-1

CLOUD COVER ON AVAILABLE LANDSAT IMAGES

San Jose Images

Path 16, Row 53

Date	Cloud Cover
01/22/74	60%
03/17/74	40%
05/28/74	80%
02/13/75	50%
03/03/75	20%
11/28/75	70%
01/26/76	50%
07/14/77	50%
08/01/77	50%
09/24/77	70%
03/14/78	60%
03/23/78	40%
04/01/78	60%
04/10/78	60%
04/19/78	30%
04/28/78	40%

Average Cloud Cover: 51%

Limon Images

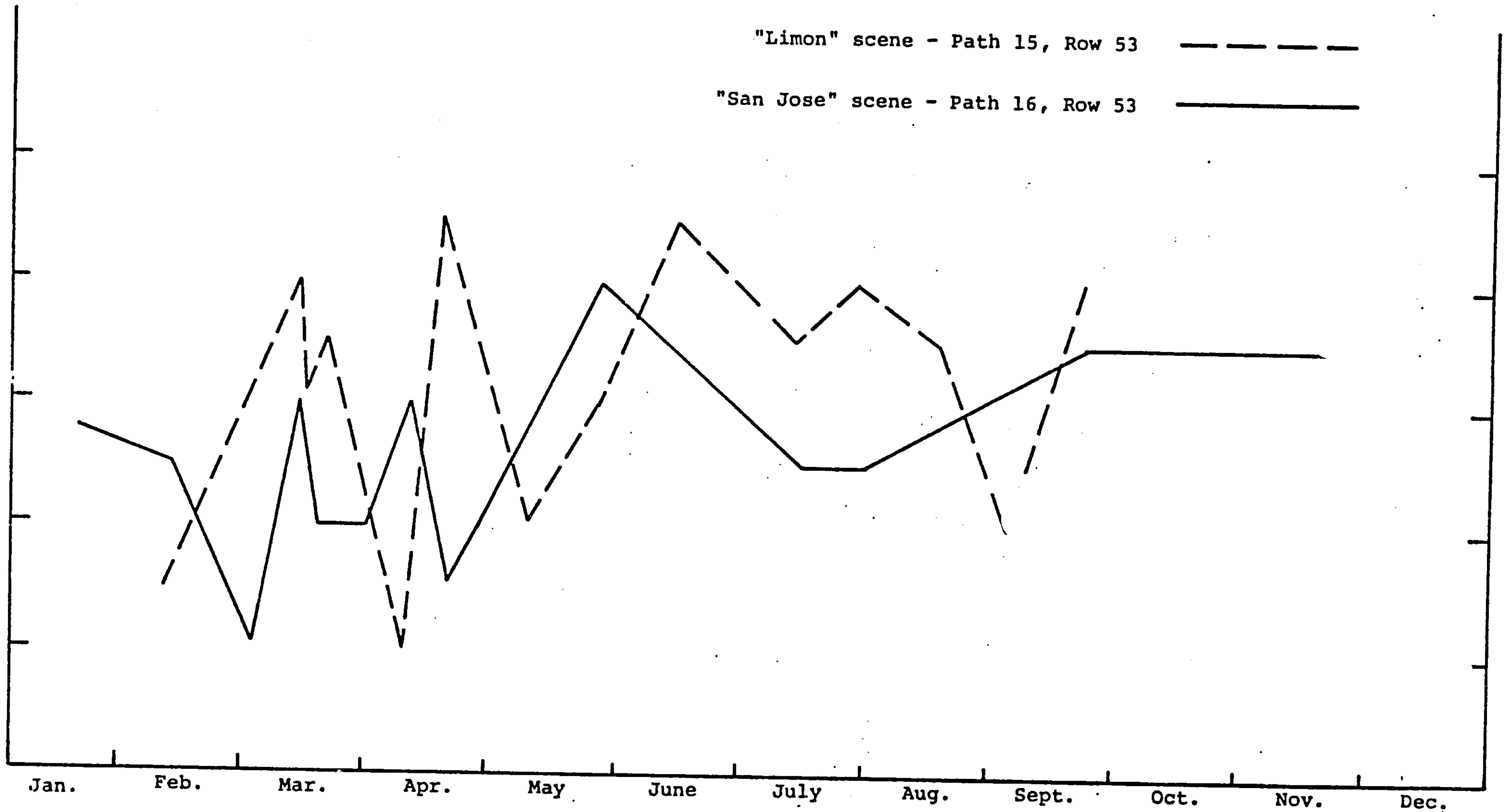
Path 15, Row 53

Date	Cloud Cover
03/16/74	60%
05/09/74	40%
05/27/74	60%
06/14/74	90%
02/12/75	30%
03/20/75	70%
03/14/76	80%
07/13/77	70%
07/31/77	80%
08/18/77	70%
09/05/77	40%
09/23/77	80%
04/09/78	20%
04/18/78	90%

Average Cloud Cover: 63%

APPENDIX C-2

AVERAGE ANNUAL CLOUD COVER


"Limon" scene - Path 15, Row 53
"San Jose" scene - Path 16, Row 53
100
80
60
40
20
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

APPENDIX C-3

LANDSAT SCENE AVAILABILITY - CENTRAL COSTA RICA

Path	Row	Date	Scene ID	Cloud Cover	Quality
15	53	06-14-74	81691151455NO	90%	0288
15	53	03-14-76	82417150645OO	80%	5858
15	53	03-16-74	81601151715NO	60%	2222
15	53	05-09-74	81655151605NO	40%	2822
15	53	02-12-75	82021151055NO	30%	8888
16	53	05-28-74	81674152115NO	80%	8288
16	53	11-28-75	82310151425OO	70%	5828
16	53	01-22-74	81548152405AO	60%	2222
16	53	02-13-75	82022151635NO	50%	8588
16	53	01-21-76	82364151345OO	50%	5555
16	53	03-17-74	81602152255NO	40%	2822
16	53	03-03-75	82040151635GO	20%	8888
15	53	07-13-77	82903144835OO	70%	5888
15	53	07-31-77	82921144735OO	80%	5888
15	53	08-18-77	82939144535OO	70%	8888
15	53	09-05-77	82957144535OO	40%	5558
15	53	09-23-77	82975155525OO	80%	8588
15	53	04-09-78	82117314445XO	20%	5588
15	53	04-18-78	83004415095XO	90%	8888
16	53	07-14-77	82904145415OO	50%	8888
16	53	08-01-77	82922145315OO	50%	8888
16	53	09-24-77	82976145015OO	70%	8888
16	53	03-14-78	83000915145XO	60%	5858
16	53	03-23-78	82115614494XO	40%	8888
16	53	04-01-78	83002715153XO	40%	8888
16	53	04-10-78	82117414504XO	60%	8888
16	53	04-19-78	83004515154XO	30%	8888
16	53	04-28-78	82119214514XO	40%	8888
15	53	03-20-75	82057151035GO	70%	5558
15	53	05-27-74	81673151525AO	60%	5888

APPENDIX C-4

EROS DATA CENTER ORDER FORM

ORDER FORM
LANDSAT STANDARD PRODUCTS

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Return Completed Form To:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
FTS: 784-7151
Comm: 605/594-6511

NAME MR / MS ______________ (FIRST) ______ (INITIAL) ______ (LAST) ______ DATE ______

COMPANY ______________ (IF BUSINESS ASSOCIATED) COMPUTER ACCOUNT NO. (IF KNOWN) ______

ADDRESS ______________ PHONE (Bus.) ______

CITY ______ STATE ______ ZIP ______ PHONE (Home) ______

SHIP TO ______________ YOUR REF NO (P.O. GOV'T ACCT OR OTHER) ______

PLEASE TYPE OR PRINT PLAINLY

SCENE IDENTIFICATION NO.	PRODUCT CODE	BAND 4	5	6	7	TOTAL BANDS	QTY.	UNIT PRICE	TOTAL PRICE

PAYMENT MADE BY

CHECK, MONEY ORDER ☐
PURCHASE ORDER ☐
GOVERNMENT ACCT ☐

*Refer to item "S" on reverse side

UNIT PRICES SUBJECT TO CHANGE

TOTAL ABOVE | A
TOTAL FROM PREVIOUS SHEETS | B
TOTAL COST | C

STANDARD PRODUCTS

BLACK AND WHITE

IMAGE SIZE	MATERIAL	[illegible]	UNIT PRICE
55.8mm (2.2 in.)	FILM POSITIVE	11	$ 8.00
55.8mm (2.2 in.)	FILM NEGATIVE	01	$10.00
18.5cm (7.3 in.)	PAPER	23	$ 8.00
18.5cm (7.3 in.)	FILM POSITIVE	13	$10.00
18.5cm (7.3 in.)	FILM NEGATIVE	03	$10.00
37.1cm (14.6 in.)	PAPER	24	$12.00
74.2cm (29.2 in.)	PAPER	26	[illegible]

1) 2) COLOR COMPOSITE GENERATION

18.5cm (7.3 in.)	PRINTING MASTER	53	$50.00

FALSE COLOR COMPOSITES

IMAGE SIZE	MATERIAL	[illegible]	UNIT PRICE
35mm Slide	FILM POSITIVE	50	$ 1.00
18.5cm (7.3 in.)	PAPER	63	$12.00
18.5cm (7.3 in.)	FILM POSITIVE	53	$15.00
37.1cm (14.6 in.)	PAPER	64	$25.00
74.2cm (29.2 in.)	PAPER	66	$50.00

2) COMPUTER COMPATIBLE TAPES (CCT)

TRACKS	BPI	MATERIAL	[illegible]	UNIT PRICE
7	800	TAPE SET	82	$200.00
9	800	TAPE SET	83	$200.00
9	1600	TAPE SET	84	$200.00

COMMENTS: ______________

1) NOTE: PRINTING MASTER IS RETAINED BY EDC. COST OF PRODUCTS FROM THIS COMPOSITE MUST BE ADDED TO TOTAL COSTS

2) NOT APPLICABLE FOR MSS BAND 8 OR RBV SUBSCENES

FORM 9-1938 (April 1978)

For Additional Information or Assistance Please Contact One of the Following Offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
FTS: 928-6045
Comm: 703/860-6045

U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: 314/364-3680

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

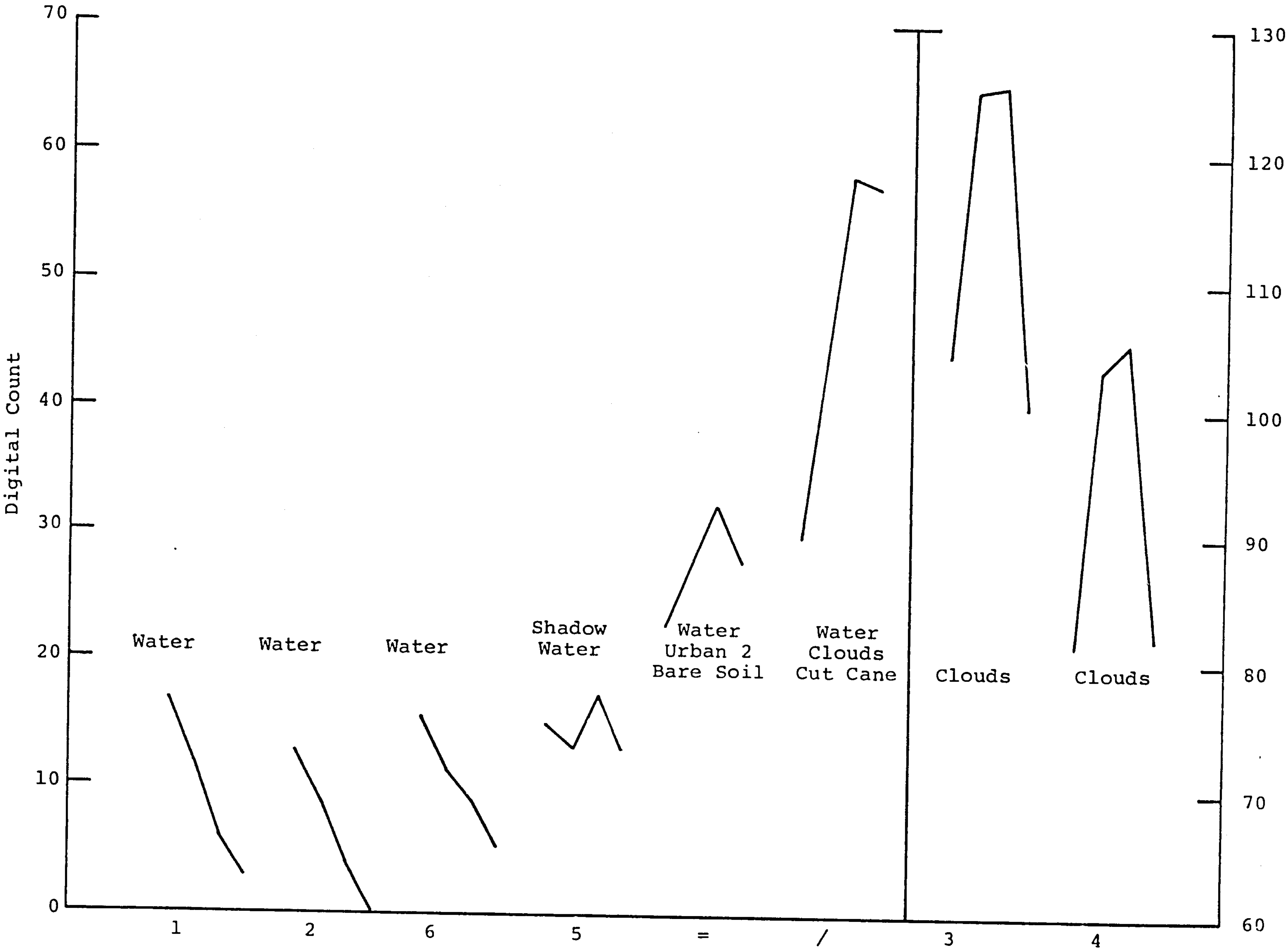
U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

U.S. Geological Survey
National Cartographic Information Center
National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY

APPENDIX C-5

SPECTRAL SIGNATURES OF 42 LANDSAT CLASSES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130
120
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80
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Water
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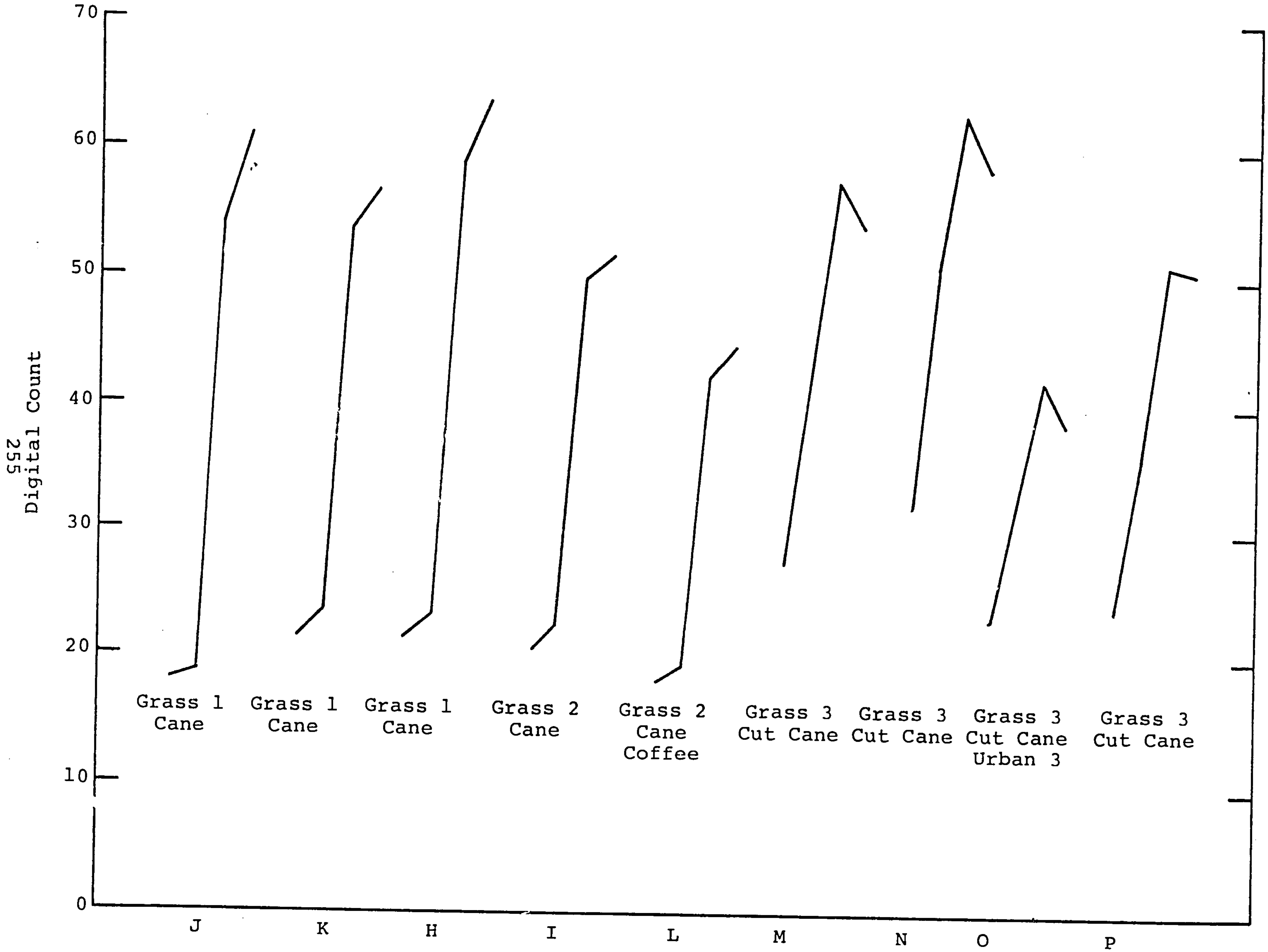
Shadow Water
Water Urban 2 Bare Soil
Water Clouds Cut Cane
Clouds
Clouds
1
2
6
5
=
/
3
4



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20
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255 Digital Count
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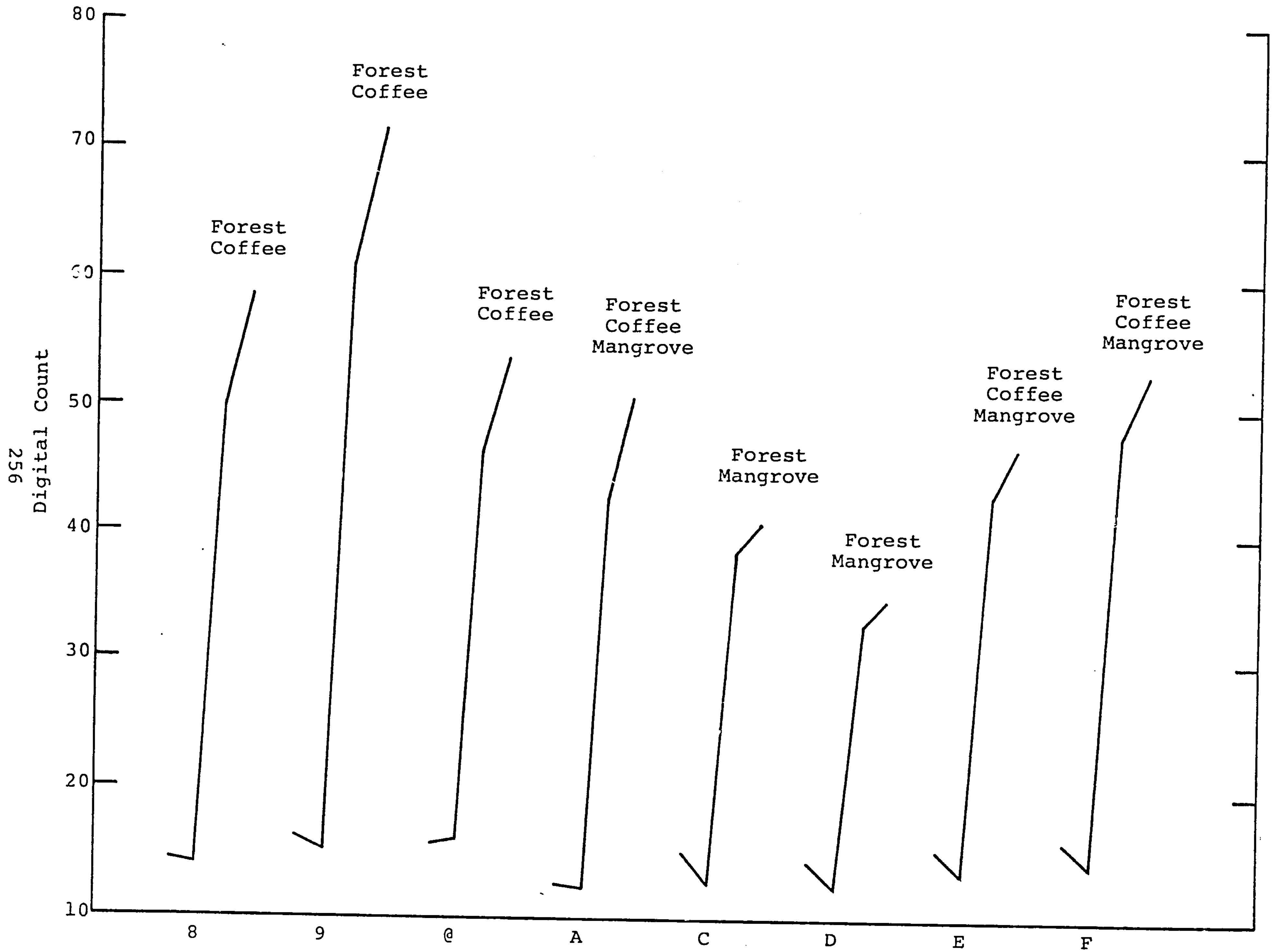
Grass 1 Cane
Grass 1 Cane
Grass 2 Cane
Grass 2 Cane Coffee
Grass 3 Cut Cane
Grass 3 Cut Cane
Grass 3 Cut Cane Urban 3
Grass 3 Cut Cane
J
K
H
I
L
M
N
O
P



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60
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40
30
20
10
256
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Forest
Coffee
Forest
Coffee
Forest
Coffee
Forest
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Mangrove
Forest
Mangrove
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Mangrove
Forest
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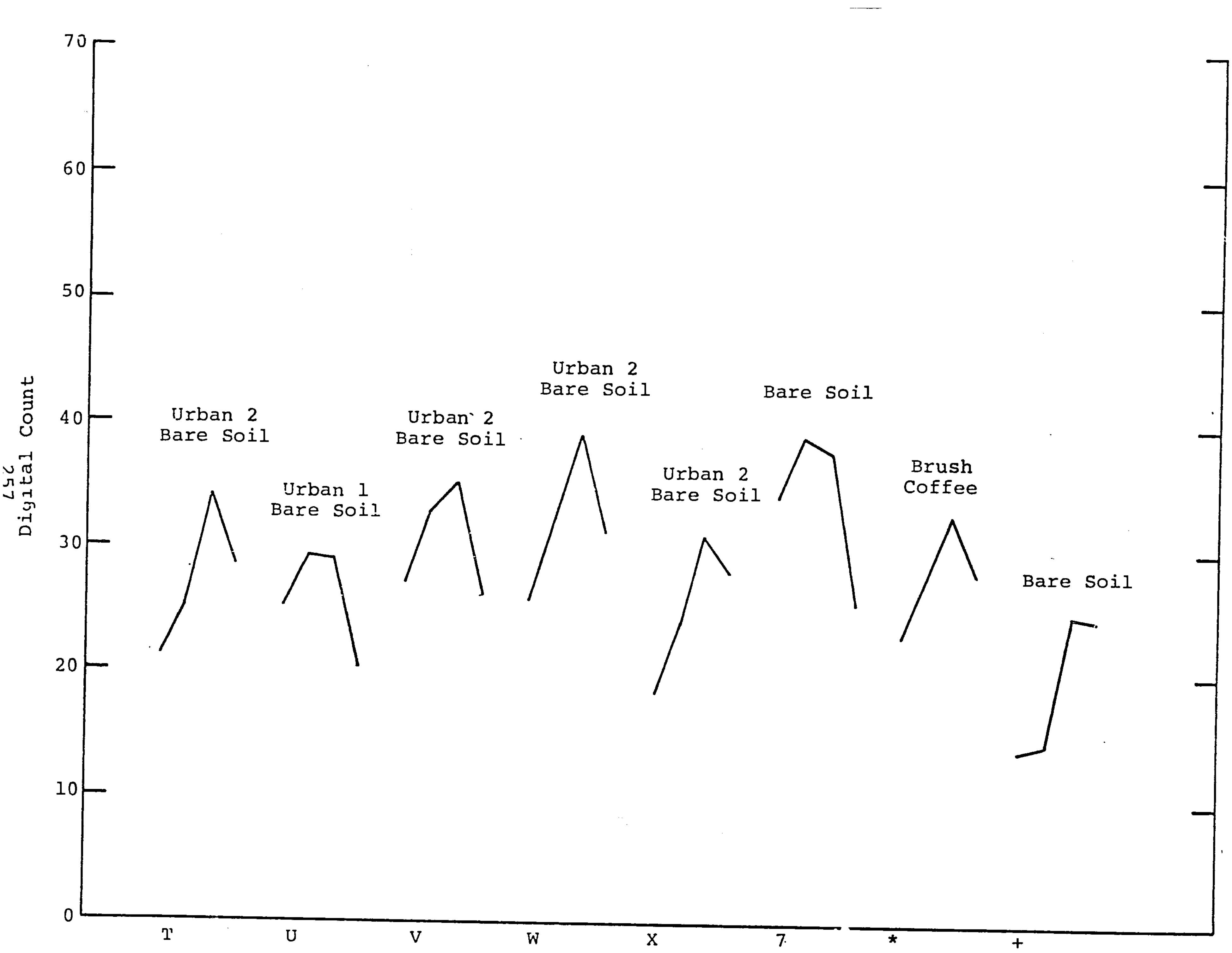
@
A
C
D
E
F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30
20
10
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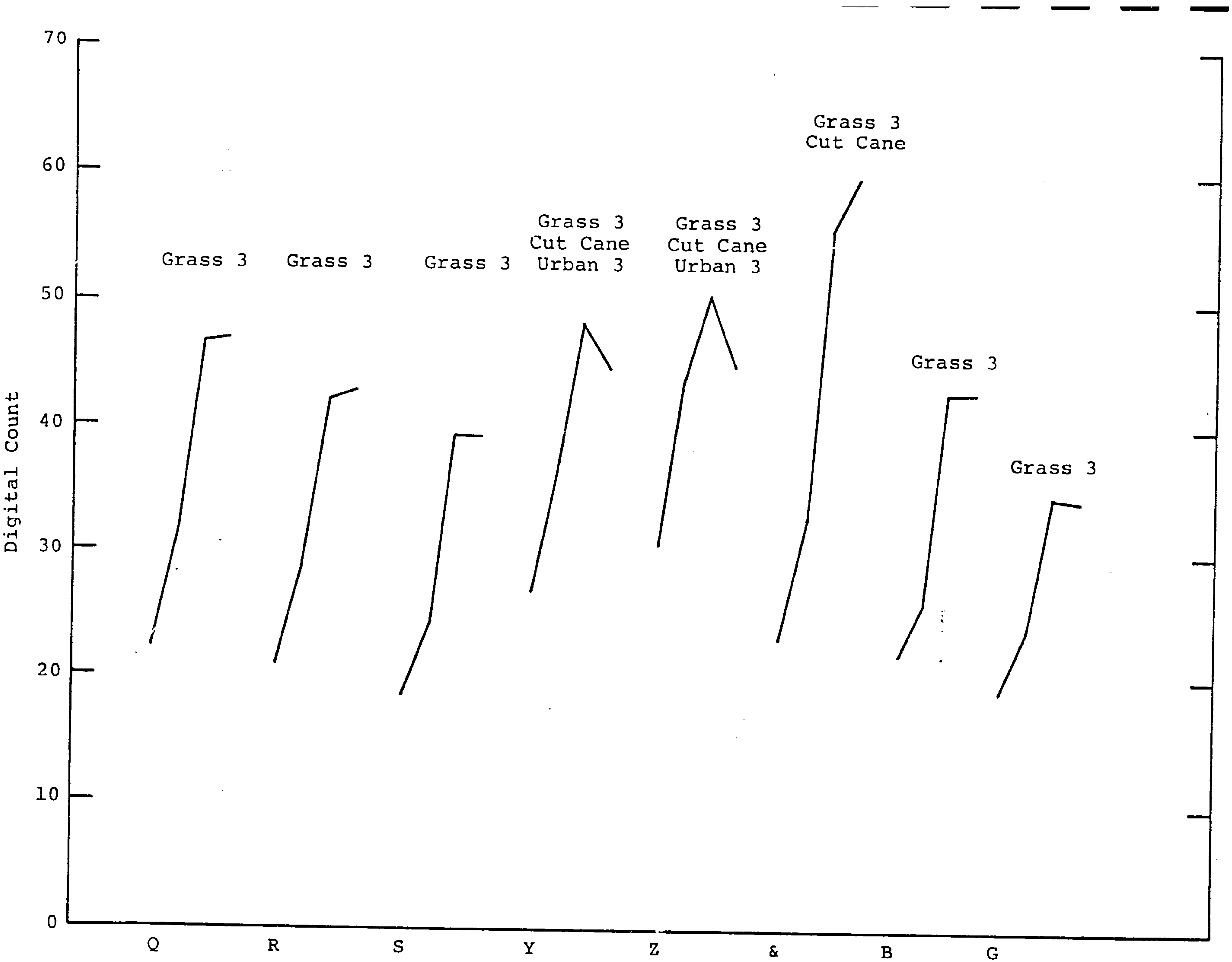
Urban 2
Bare Soil
Urban 1
Bare Soil
Urban 2
Bare Soil
Urban 2
Bare Soil
Urban 2
Bare Soil
Bare Soil
Brush
Coffee
Bare Soil
T
U
V
W
X
7
*
+


Digital Count
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40
30
20
10
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Grass 3
Grass 3
Grass 3
Grass 3
Cut Cane
Urban 3
Grass 3
Cut Cane
Urban 3
Grass 3
Cut Cane
Grass 3
Grass 3
Q
R
S
Y
Z
&
B
G

APPENDIX C-6

LANDSAT GEOMETRIC CORRECTION CONTROL POINTS

Point	Sheet	Latitude	Longitude
A	Nicoya	10° 6.5' N	85° 7.4' W
B	Nicoya	9° 42.7' N	85° 0.9' W
C	Nicoya	10° 25.7' N	85° 5.6' W
D	Quepos	9° 37.9' N	84° 40.2' W
E	Quepos	9° 38.6' N	84° 17.8' W
F	San Jose	9° 58.7' N	84° 51.3' W
G	San Jose	10° 23.9' N	84° 46.5' W
H	San Jose	10° 12.2' N	84° 43.4' W
I	San Jose	9° 54.7' N	84° 50.0' W
J	San Jose	9° 45.5' N	84° 6.7' W
K	San Jose	9° 56.8' N	84° 13.4' W
L	San Jose	10° 11.3' N	84° 13.8' W
M	San Jose	10° 29.2' N	84° 27.5' W
N	San Jose	10° 13.8' N	83° 53.5' W
O	San Jose	9° 58.6' N	84° 3.2' W

APPENDIX C-7

ROW/COLUMN COORDINATES FOR 1:50,000 QUAD SHEETS

	ROW		COLUMN	
	Start	End	Start	End
Tarcoles	444	530	339	554
Barranca	358	444	338	553
Abra	360	446	772	987
Rio Grande	359	445	555	770
Golfo	357	443	121	336
Naranjo	273	359	554	769
Barba	274	360	771	986

APPENDIX C-8

PERCENTAGE LAND COVER BY COMPUTER CLASSIFICATION FOR 1:50,000 QUAD SHEETS

Land Cover Class	Abra	Barba	Barranca	Golfo	Naranjo	Rio Grande	Tarcoles	Total Project Area
	1:50,000 Quad Sheet							
Bare Soil	9.91	4.21	9.42	11.00	7.26	15.95	11.06	10.61
Forest	2.93	13.19	1.42	1.64	6.46	28.36	21.61	19.59
Brush	5.48	5.00	8.60	9.77	7.78	13.70	14.87	8.61
Grass 1	2.30	8.86	0.38	0.39	3.10	0.66	6.70	9.00
Grass 2	6.85	12.66	8.69	7.27	5.12	11.39	24.63	11.61
Grass 3	5.13	14.14	67.82	57.46	28.32	54.67	17.49	30.06
Urban 1	0.58	0.01	0	0	0.01	0	0	0.04
Urban 2	10.32	1.76	0.18	1.05	0.51	0.05	0	0.81
Urban 3	2.78	0.39	0.09	0.02	0.16	0.03	0	0.22
Coffee	33.72	38.18	0	0	27.00	0.32	0	6.80
Cane	0	1.39	0.71	1.64	10.19	0.28	0.33	1.20
Cut Cane	0	0.19	1.28	2.10	4.10	0.13	0.06	1.03
Mangrove	0	0	1.41	7.65	0	0	3.26	0.44

APPENDIX D-1

1:200,000 SOIL MAP LEGEND, SAN JOSE MAP SHEET

Symbol	Principal Soil Type	Associated Soil Type
A3	Typic Palehumults	Aeric Tropaquepts
A5	Vertic Tropaquepts	
A6	Aquic Ustropepts	
A7	Aeric Tropic Fluvaquents	
A8	Typic Tropaquepts	
A11	Typic Troporthents	
B3	Fluvaquentic Hapludolls	Fluvaquentic Haplaquolls
B4	Typic Sulfaquepts	Tropic Fluvaquept
B6	Hydric Dystrandepts	
B9	Fluventic Ustropepts	Typic Ustifluvents
B11	Andic Dystropepts	Fluventic Dystropepts
B12	Typic Hydraquents	Tropic Fluvaquent Histic Fluvaquent
C1	Typic Pellusterts	Ustic Humitropepts Vertic Ustropepts
C2	Typic Palehumults	
C3	Aquic Dystrandepts	
C4	Aquic Dystrandepts	Typic Dystrandepts
C6	Andic Ustic Humitropepts	Aeric Tropaquepts
C7	Oxic Dystropepts	Aeric Tropaquepts
C8	Andic Dystropepts	
D3	Typic Tropohumults	Typic Humitropepts
D4	Typic Paleudults	
D7	Typic Dystrandepts	Typic Vitrandepts
D8	Typic Humitropepts	Andic Humitropepts Oxic Dystropepts
D9	Andic Humitropepts	Andic Tropohumults Oxic Dystropepts
D10	Fluventic Dystropepts	
E2	Typic Placandepts	Typic Dystrandepts
E3	Lithic Dystrandepts	
E6	Lithic Dystropepts	Typic Dystropepts
X1	Typic Dystrandepts	Typic Eutrandepts
X2	Fluventic Humitropepts	Aquic Humitropepts Typic Humitropepts
X3	Ustic Humitropepts	Andic Ustic Humitropepts
X4	Fluventic Ustropepts	Fluventic Haplustolls
X5	Typic Dystropepts	Typic Troporthents Lithic Dystropepts
X6	Ustic Dystropepts	Ultic Haplustalf
X7	Lithic Ustorthents	

APPENDIX D-2

LEYENDA GEOLOGICA MAPA COSTA RICA

Qa Aluvion

Qvl Depositos laharicos (Lavina) extensos

Qpt Depositos marinos clasticos (Fm.Armuelles) y continentales (terrazas) del Pleistoceno

Tp Depositos marinos clasticos y arrecifes pequenos (Fm. Charco Azul, Moin y arrecifes en costa atlantica) y depositos continentales-litorales (Fm. Suretka)

Tm Depositos marinos paralicos con facies locales de caliza (Fm. Gutan, Venado, Punta Carballo, Montezuma, Curre y Burica.)

Tom Depositos marinos clasticos finos y localmente calizas (Fm. Uscari.)

To Depositos marinos clasticos del Oligoceno, incluyendo possiblemente rocas un poco mas antiguas y mas jovenes (Fm. Senosri, Terraba, Masachapa.)

Tepc Rocas clasticas (Fm. Brito, Tuis, Las Palmas) y calizas (Fm. Las Animas, David y Barra Honda) con intercalacion de rocas volcanicas

TT Peridotita serpentinizada (Santa Elena) posiblemente de edad Cretacica, pero aun no definida

K Rocas clasticas y calizas del Campaniano y Maastrichtiano (Fm. Rivas, Sabana Grande, Golfito, Changuinola), con intercalaciones de rocas volcanicas

Qv2 Ignimbritas andesiticas (Valle Central Orotina), daciticas (Fm. Bagaces), y riodaciticas (Fm. Liberia) con depositos lacustres y Lahares (lavina) asociados

Qv3 Edificios volcanicos (lavas, rocas piroclasticas y lahares pequenos, principalmente andesitas y en menor grado basaltos; localmente pomez riodacitica.)

Tv Rocas volcanicas variadas, andesiticas y basalticas incluyendo lavas, rocas piroclasticas, ignimbritas (Fm. Aquacate, Doan, Paso Real, Pey y Cerros Curena.)

Ti Rocas intrusivas principalmente miocenicas, incluye cuarzodiorita, granodiorita, y menor proporcion granito y gabro

Ki Rocas intrusivas del cretacio superior, puede incluir otras mas jovenes, incluye gabros, diabasas y en menor proporcion diorita

Kvs Rocas volcanicas y sedimentarias (Complejo de Nicoya) anteriores al Campaniano Superior

Fecha: 1968 Escala: 1:700,000

APPENDIX D-3

LEYENDA GEOLOGICA - CORRELACIONES PROBABLES
MAPA HOJA BARRANCA

Age	Formation		Description
Cuaternario	Qal	Aluvion	
	fmE	Formacion Esparta	Bloques sanos de lava y cuarzo, semiredondeados en tierra roja amarillenta, ligeramente arcillosa.
Plio-Pleistoceno	fmO	Formacion Orotina	Ignimbritas.
	fmT	Formacion Tivives	Bloques sanos de lavas, angulares y subangulares en una matriz gris, tobacea, sana, pero alterada y arcillificada en superficie.
Mio-Plioceno	GA	Grupo Aguacate	Coladas de basalto y andesitas interestratificadas con mantos de tobas, ignimbritas y brechas volcanicas y aglomerados
Mioceno Superior	fmPC	Formacion Punta Carballo	Arenisca y conglomerado gris, verdoso, levemente calcareos, con o sin ofsiles. Areniscas y limolitas marron, tobaceas alternando con brechas sedimentarias y volcanicas.
Pre-eoceno	CN	Complejo de Nicoya	Calizas siliceas no fosiliferas y basaltos.

Ejecuto y Reviso: Ing. Rodolfo Madrigal G.
Escala: 1:50,000
Fecha: Julio de 1967

APPENDIX D-4

LEYENDA GEOLOGICA - CORRELACIONES PROBABLES
MAPA BASICO RIO GRANDE

Age	Formation	
Cuaternario-Reciente	Qal	Aluvion
Cuaternario-Pleistoceno	TQ-v	Rocas volcanicas lahares y aluviones no diferenciados
	TQ-o	Ignimbritas de orotina
	Q-spa	Lavina de San Pablo
	Q-spe	Lavina de San Pedro
Terciario-Plioceno-Superior	TQ-t Tmp-a	Form. turrubares Formacion aguacate
Terciario-Plioceno-Medio	Tm-c	Formacion coris
Terciaric-Plioceno-Interior	Tm-t	Formacion turrucares
Terciario-Oligoceno	Tmo-t	Formacion terraba
Cretacico	K-cn?	Complejo de nicoya

Ejecuto: Rolando Castillo
Escala: 1:50,000
Fecha: 1970

APPENDIX D-5

LEYENDA ECOLOGICO MAPA REPUBLICA DE COSTA RICA

bs-T	Tropical dry forest
bs-T	Tropical dry forest, moist province transition
bh-T	Tropical moist forest
bh-T	Tropical moist forest, perhumid province transition
bh-T	Tropical moist forest, premontane belt transition
bmh-T	Tropical wet forest
bmh-T	Tropical wet forest, premontane belt transition
bh-P	Premontane moist forest
bh-P	Premontane moist forest, basal belt transition
bmh-P	Premontane wet forest
bmh-P	Premontane wet forest, basal belt transition
bmh-P	Premontane wet forest, rain forest transition
bp-P	Premontane rain forest
bh-MB	Lower montane moist forest
bmh-MB	Lower montane wet forest
bp-MB	Lower montane rain forest
bmh-M	Montane wet forest
bp-M	Montane rain forest
pp-SA	Subalpine rain paramo

Fecha: 1969 Escala: 1:750,000 Ejecuto: Joseph A. Tosi, Jr.

APPENDIX D-6

LEGEND OF BIOPHYSICAL UNITS FOR "LAND MANAGEMENT" MAP

1. Ustic and Typic Deptropepts occurring in warm wet climates below 1,000 meters elevation on nearly level to undulating Quaternary volcanics. Apt for perennials and intensive pasture.

2. Typic Tropaquents and Hydraquents occurring in warm wet climates below 1,000 meters elevation on Quaternary alluvium on level to nearly level wet soils, wet lands and swamps. In the dry season some areas can be used for extensive grazing.

3. Typic Tropopsaments occurring in warm moist climates below 1,000 meters elevation on level to nearly level beach sands which are subject to fluctuating high water tables due to the tides. Some areas are swamps. Most useful for tourism.

4. Fluventic Ustropepts and other fluvial soils in moist warm climates below 1,000 meters elevation on level to nearly level Quaternary alluvium. Usually deep fertile soils suitable for intensive agriculture.

5. Typic Troporthents in warm moist climates below 1,000 meters elevation on nearly level Quaternary alluvium with frequent occurrences of shallow bedrock. It is suitable for very intensive agriculture.

6. Typic Tropohumults and Palehumults in warm wet climates below 1,000 meters elevation on nearly level to undulating Quaternary alluvium dissected with numerous shallow valleys. Suitable for moderate and intensive agriculture.

7. Hydric Dystrandepts and Andic Humitropepts in warm wet climates below 1,000 meters elevation on undulating Quaternary lava flows with incipient dissestion. Suitable for extensive agriculture.

8. Typic Tropohumults and Palehumults in warm moist climates below 1,000 meters elevation on undulating to rolling fine Teriary marine clastics and interbedded limestones.

9. Typic and Andic Humitropepts in tepid rain forests between 1,000 and 2,000 meters elevation on steep medium and coarse tertiary marine clastics. Suitable for forestry.

10. Typic Tropohumults and Palehumults in warm moist climates below 1,000 meters elevation on steep rolling and highly andesitic and basaltic Tertiary volcanic clastics. Suitable for forestry and tree crops like pejiballe, macadamia nut, etc.

11. Typic Tropohumults and Palehumults in warm wet climates below 1,000 meters elevation on steep foot hills of Tertiary volcanic clastics. Suitable for forestry.

12. Typic Tropohumults and Palehumults in tepid rainy climates between 1,000 and 2,000 meters elevation on steep mountainous quartz-diorite and granodiorite Tertiary intrusives. Suitable for forestry.

13. Typic Tropohumults and Palehumults in rainy tepid climates between 1,000 and 2,000 meters elevation on steep mountaineus adesitic and basaltic Tertiary clastics. Suitable for forestry.

15. Typic Tropohumults and Palehumults in wet tepid climates between 1,000 and 2,000 meters elevation on steep slopes of volcanos with straight narrow deep drainages. Materials are composed of Quaternary ashes and pyroclastics. Suitable for perennial tree crops and forests.

16. Andic Humitropeps and Typic Dystrandepts in warm wet climates below 1,000 meters elevation on undulating to rolling Quaternary ash and pyroclastic volcanics. Suitable for extensive agriculture, perennial tree crops or forestry.

17. Typic Dystrandepts in warm wet climates below 1,000 meters elevation on steep hilly to mountainous ash and pyroclastic Quaternary volcanics. Suitable for forestry and watershed protection.

18. Typic Tropohumults and Palehumults in wet tepid climates between 1,000 and 2,000 meters elevation on hilly to steep andesitic and basaltic Tertiary volcanic clastics located in a basin high in the mountains. Suitable for extensive grazing and forestry.

19. Lithic Ustorthents and Dystropepts in moist tepid climates between 1,000 and 2,000 meters elevation on very steep mountainous medium and coarse Tertiary marine clastics with shallow bedrock. Suitable for forestry and watershed protection.

20. Typic Dystropepts in moist tepid climates between 1,000 and 2,000 meters elevation on steep mountainous medium and coarse Tertiary marine clastics. Suitable for forestry and watershed protection.

21. Typic Dystropepts in moist warm climates below 1,000 meters elevation on steep mountainous medium and coarse Tertiary marine clastics. Suitable for forestry and watershed protection.

22. Typic Dystropepts in wet tepid climates between 2,000 and 3,000 meters elevation on steep mountainous medium and coarse Tertiary marine clastics. Suitable for forestry.

23. Typic Dystrandepts in cool rainy climates above 3,000 meters elevation on steep volcanic summit of Quaternary volcanic ashes and pyroclastics. Suitable for forestry.

24. Typic and Ustic Dystropepts on the steep slopes and Typic and Aquic Paleudults on the interflows in warm moist climates below 1,000 meters elevation on hilly to steep dissected plains of Quaternary pyroclastics. Suitable for extensive agriculture, perennial tree crops and extensive pasture on the interflows and forests on the steep slopes.

25. Typic Pellusterts in moist warm climates below 1,000 meters elevation on dominantly nearly level Quaternary volcanic ashes and pyroclastics. Suitable for intensive agriculture.

26. Typic Humitropepts in wet tepid climates between 1,000 and 2,000 meters elevation on hilly to steep Cretaceous marine clastics and limestones. Suitable for extensive grazing and forests.

27. Typic and Lithic Dystropepts in moist warm climates below 1,000 meters on steep Cretaceous marine clastics and limestones. Suitable for forestry and watershed protection. This unit has shallow to thin soils.

28. Typic Tropohumults in moist warm climates below 1,000 meters elevation on steep Cretaceous marine clastics and limestone. Suitable for forestry.

29. Ustic and Typic Dystropepts as well as Typic Troporthents in moist warm climates below 1,000 meters elevation on steep andesitic and basaltic Tertiary volcanic clastics. Suitable for forestry.

30. Typic Sulfaquepts in moist wet climates on level coastal alluvium. These are the mangrove swamps and the high watertable fluctuates with the tides. Suitable for mangrove forests.

31. Ustic Dystropepts in moist warm climates below 1,000 meters elevation on hilly Quaternary pyroclastics. Suitable for perennial tree crops and forests.

32. Typic Dystrandepts in warm moist climates below 1,000 meters elevation on hilly to steep Quaternary volcanic ashes and pyroclastics. Suitable for forestry.

33. Ustic Dystropepts in warm wet climates below 1,000 meters elevation on steep Quaternary volcanic ashes and pyroclastics. Suitable for forestry and watershed protection.

34. Andic Humitropepts and Typic Dystrandepts in wet tepid climates between 1,000 and 2,000 meters elevation on steep Quaternary volcanic ashes and pyroclastics. Suitable for forestry, watershed protection, and extensive agriculture with good conservation practices.

35. Hydric Dystrandepts in moist tepid climates between 1,000 and 2,000 meters elevation on hilly and steep Quaternary volcanic ashes and pyroclastics. Suitable for perennial tree crops and forestry.

APPENDIX E

LAND USE AGGREGATIONS - CANTON 1, SAN JOSE

Distritos of Canton 1 - San Jose

	LAND-USE CLASSES: Area in ha																
Distrito	111	112	113	12	13	14	15	16	171	172	221	24	31	34	35	41	73	Total
Carmen	--	44.6	44.0	13.8	--	4.5	--	17.5	8.1	3.2	--	8.1	--	--	--	--	--	143.8
Merced	2.0	--	115.5	55.1	3.2			12.8	1.9	31.4	--	--	--	--	--	--	--	201.9
Hospital	--	9.3	99.8	71.7	31.7	23.1	--	54.7	10.1	3.8	--	20.2	--	--	--	--	--	324.4
Catedral	9.5	56.9	139.7	6.7	--	--	12.9	9.7	3.3	2.5	--	7.1	--	--	--	--	--	248.3
Zapote	16.9	159.1	--	--	4.7	--	--	1.8	4.0	44.1	--	40.7	--	--	--	--	--	271.2
San Francisco de dos Rios	--	124.5	--	--	20.7	--	--		4.1	12.8	--	101.5	--	--	--	--	--	263.6
Uruca	5.8	31.8	14.1	2.7	43.4	10.7	122.4	39.3	37.8	63.8	15.8	178.2	115.2	7.2	2.7	50.1	92.1	825.9
Mata Redonda	--	141.6	--	2.3	4.5	24.1	--	23.3	68.5	11.9	--	85.8	--	--	--	--	2.8	364.8
Pavas	--	22.2	27.3	--	59.1	32.6	4.0	35.9	7.6	306.7	--	357.4	57.2	--	19.8	--	3.7	933.5
Hatillo	--	34.7	178.8	--	16.1	--	--	3.4	3.3	45.2	7.2	149.1	--	--	--	--	--	437.8
San Sebastian	--	200.9	--	--	14.1	--	--	2.9	1.8	--	44.7	122.2	--	--	--	--	--	386.6
TOTALS	34.2	825.6	618.9	152.3	197.5	95.0	139.3	201.3	150.5	525.4	67.7	1,050.3	172.4	7.2	22.5	50.1	98.6	4,401.8
PERCENT	.7	18.7	14.1	3.5	4.5	2.2	3.2	4.6	3.4	11.9	1.5	23.8	3.9	.1	.5	1.4	2.2	100.0