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THE UTILITY, COST, AND EFFECTIVENESS OF REMOTE SENSING FOR FOREST AND URBAN SECTOR ASSESSMENT IN COSTA RICA

Resources
Development
Associates

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Resources Development Associates, P.O.Box 239, Los Altos, Calif. 94022

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1.0 PROJECT SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

The nation of Costa Rica is facing a resources crises in the near future from land conversion pressures. Urban land use is expanding at a rapid rate, primarily onto high value, very productive agricultural lands. Agriculture and rangeland uses are expanding onto forested lands in nearly every sector.

This expansion in itself is not inconsistent with national goals of production and development, but the uncontrolled, unmonitored manner in which it is happening is counter to wise use of the land in many cases. In order that proper planning be executed, information concerning the extent, location, and condition of these resources and their current level of exploitation is required. Remote sensing technology offers a cost-effective means of gathering land resource information of this type.

The Agency for International Development and the Government of Costa Rica requested that Resources Development Associates (RDA) develop, test, and demonstrate various technical approaches to resource assessment in Costa Rica. This report details the actions and findings resulting from this demonstration project.

An aircraft and satellite remote sensing data collection and analysis project was undertaken to determine the most cost-effective approach to the development of an appropriate resources information base. In the forestry sector of this project, manual interpretation of panchromatic, color, and color infrared aircraft photography and both visual and digital products from the LANDSAT satellite were compared with regard to collection timing, cost, and effectiveness. Information needs and detail were assessed for each area of interest; forest, urban use, range and agriculture.

The same types of aircraft and satellite products were also employed in a demonstration study of urban areas in the Meseta Central. A set of land-use/land-cover maps was prepared using the aircraft data as a data source. Land-use and land-cover polygons were recorded. Areas of land use were measured and

aggregated by administrative units. Satellite digital data was used to prepare a second set of land-use and land-cover maps. The two classification systems varied with the product but both were devised to provide desired information on the current land-use situation as well as to provide an infrastructure for monitoring future changes.

Results of these studies provide necessary information for decisions concerning selection of optimum combinations of data collection and analysis techniques as well as map products to be used in a pilot study of land use and land change in Costa Rica.

Near the completion of the project, a demonstration and workshop was conducted in Costa Rica. Through this interaction, project results were conveyed to Costa Rican professional and technical personnel and, in turn, the RDA staff obtained valuable feedback and insights into the application of remote sensing to the problems at hand.

This report will summarize methods, techniques, and products explored, and make recommendations for the Costa Rican Pilot and National Programs. In addition, areas that need further exploration and better definition will be identified.

Conclusions and recommendations for the forest and urban sectors will be discussed separately. Conclusions are based on insights gained throughout the demonstration experiment phase. Recommendations are provided for the necessary applications of appropriate tools and techniques for a comprehensive resources assessment program in Costa Rica.

1.1 Conclusions for the Forest Sector

The conclusions reached by RDA concerning the forest sector are:

1. Black and white, natural color, and color infrared aerial photography each have the potential to provide the type of information that is needed for both the establishment of a data base necessary for intensive forest management, and for forest cover and forest resources monitoring.
2. Both natural color and color infrared film types improve and facilitate interpretation of forest cover as compared to black and white photography.
3. Multispectral systems pose major acquisition costs and problems with little or no increase in benefits over the other three film types.
4. Natural color is superior at low levels for interpretation of forest cover and forest types, but color infrared is superior at medium levels, primarily due to its haze-cutting abilities.
5. Medium scale photography is sufficient for Level III (see Section 3.0) classification, but may need to be supplemented by large scale photography and minimum ground truth for verification. The map scale of 1:50,000 presently in use in Costa Rica complements and is compatible with Level III applications. The medium scale photography is more efficiently and accurately transferred to the 1:50,000 map scale than low level photography.
6. Costa Rica does have the in-country cability to acquire high quality color and color infrared photography at both scales.
7. Visually interpreted satellite imagery is inadequate for forest cover delineation at the level of detail required in Costa Rica. However, it may have value in other aspects of resource management; e.g., hydrological investigation, physiographic mapping, etc.
8. Digital analysis of the satellite data does provide accurate Level I classification of land cover and a potential forest cover monitoring system. Level II data can be obtained in some cases. Level I information is needed immediately for general planning purposes.

9. Digital classification of satellite data cannot provide the level of detail for the compilation of a detailed data base for intensive forest management; e.g., forest associations, stand density, tree heights, timber volumes, etc.

10. The most appropriate format scale for the forest cover Level I classification would be 1:200,000. This matches a Costa Rican national mapping scale and will be easier for the foresters to use.

11. Cloud cover is a definite problem for acquisition of high quality remotely sensed data in Costa Rica. An investigation should be made to determine the most probable dates for acquiring relatively cloud-free data and thus the frequency of updating resource information.

In summary, digitally analyzed LANDSAT data appears to be the most cost-effective alternative for preparation of Level I forest cover maps at 1:200,000 scale. Color infrared aerial photography at an acquisition scale of 1:40,000 would appear to be the most cost-effective tool for development of Level II and III forest use maps

1.2 Recommendations for the Forest Sector

In light of the experience gained in this project as detailed in the conclusions, the following recommendations can be made:

1. The Costa Rican governmental agencies involved in forest land management should consider acquiring color and/or color infrared aerial photography systematically at a pace that can be efficiently handled by Costa Rican foresters, and should provide for training of personnel and acquisition of equipment needed for photo interpretation, photo handling, and the building of a forest resource data base. The film processing could be done in the United States if the national demand for this type of service does not warrant an in-country capability of this type.

2. The Costa Rican Government should start planning for intensive forest management supported by the medium and large scale photographic techniques outlined within this report. The medium scale photography should form the basis for the data acquisition phase due to its cost-effectiveness and ease of data transfer to the 1:50,000 map base.

3. The Government should utilize the LANDSAT satellite imagery in a digital format for an immediate assessment of the forest cover and resource, and as a annual or bi-annual monitoring tool.

4. As preparation for a national project including points 1, 2 and 3, a pilot project should be initiated that will further develop the tools, techniques and training necessary for such an effort. The project should be of sufficient size to address the major problems that will arise from such a national project and provide sufficient training for Costa Rican personnel to ensure an in-country capability to continue a comprehensive resource assessment program.

1.3 Conclusions for the Urban Sector

The conclusions reached by RDA concerning the urban sector are:

1. While all the data employed in the demonstration project are generally satisfactory, experience dictates that best results were obtained by:

   a. Using natural color, large photo scale transparencies for land-use mapping in the built-up areas. The natural color of such features as rooftops were more familiar to the interpreter and thus easier to use, faster, and therefore less costly in terms of labor.

   b. Using color infrared, large photo-scale transparencies for classification of vegetation in the rural-urban fringe areas. Color infrared proved the most effective for identifying the subtle differences necessary to classify stages of abandonment of coffee land.

2. The base map series designed and tested proved satisfactory. The device of quartering the 1:50,000 series into 1:25,000 sheets is compatible with the existing mapping program, is the lowest cost method of providing necessarily large scale, and is compatible with the detail of the classification system employed.

3. The classification system presents an optimum level of detail. The minimum mapping unit of one hectare is also a good compromise to meet the goals of the study. While it is not small enough to suit the detail of mapping in the old central city, it is a good choice for rural-urban fringe uses, the principal area of concern as urbanization makes incursions into valuable agricultural land. The classification system, worked out in cooperation with INVU colleagues, has been refined to a point where it would serve well the needs of the pilot project.

4. The system of area measurement and aggregation by administrative reporting unit (the Distrito) is satisfactory.

5. The mapping of land use from aerial photography through the photo interpretation process and by applying it to base maps of 1:25,000 scale is essential to provide a baseline and land-use inventory. Future changes can be measured against this highly accurate base. Such information has high potential value for policy making.

6. Computer processing of LANDSAT digital data produced about the same quality results in Costa Rica as had been experienced in tests conducted in U. S. urban areas. The slight variations on urban land-use types in Costa Rica provided no special problems to the functioning of the system. Some classification problems were encountered which have been of concern to similar efforts elsewhere. Further experience in Costa Rica should reduce these spectral confusion problems to a minimum. It is felt that a significant achievement was made in a high quality distinction between rural and urban land uses. This permitted the further manipulation of the data to prepare maps of urbanized area delimitation and urban and urban-rural fringe growth regions. Minimum job costs for computer processing of LANDSAT data may pose a problem for its use in small-are urban studies in Costa Rica.

In summary, if the urban sector must absorb the total minimum-job costs for computer processing, then digitally analyzed LANDSAT data will <u>not</u> be cost-effective for typical urban application in Costa Rica. On the basis of currently available cost information,

manual interpretation of color film at a scale of 1:20,000 would be the recommended alternative for the production of 1:50,000 scale Level I/II urban maps as well as for the more detailed 1:25,000 scale Level III/IV maps.

These conclusions are highly sensitive to small differences in efficiency of interpretation and analysis, and should be carefully reviewed during the pilot project stage. Similarly, if the basic costs of LANDSAT data acquisition and processing can be shared with another resource sector, then this approach may become more feasible from a cost standpoint.

1.4 Recommendations for the Urban Sector

The sorting out of results, as given above, leads to the offering of specific recommendations for the future and, in particular, for the pilot phase of the study. They are:

1. Continue with systems developed in the demonstration project, namely:

    a. The baseline and land-use inventory as derived from aerial photo interpretation and plotted on base maps of 1:25,000 for areas which are urban and/or urbanizing. Similar mapping at 1:50,000 would be satisfactory for rural areas.

    b. Continue to acquire and use natural color photography (in diapositive form) of fairly large scale for built-up areas. Color infrared is superior for urban areas.

    c. Acquire low altitude oblique photography in a systematic way to serve as support for interpretation of vertical aerial photography. This is especially necessary for urban areas where building height may be important and where the extra detail is required to distinguish between such problems areas as industrial and commercial land uses.

d. Continue the systematic base-map series. Scribing and preparation of registered separation sheets should also be continued since the method is compatible with those used in IGN and would permit, if desired, the publication of maps. Further, the maps would be compatible with a 1:25,000 series of topographic maps if they were to be produced. Stable-based mapping materials should be used throughout the process.

2. Continue working with LANDSAT digital data. The possible availability of new data from LANDSAT 3, on a periodic basis, would provide for the sequential mapping and monitoring of the areal extent of urban areas. Use of these data in the next few years would also give the requisite experience to make beneficial use of the finer resolution (30 meters instead of 80) planned for LANDSAT 4. The results of processing new data in the next year could be compared to the 1975 maps produced for the demonstration phase. Change could then be measured providing graphic evidence to be used by policy makers.

3. Change detection should also be accomplished by comparing aerial photographs of a few years previous, where available, with those recently acquired. Maps of change could be made which would further define the process and rate of change.

4. Provide various forms of ground-collected data such as soils, slope, productivity, potential hazards, and land values to be used in conjunction with land-use data in the development of a geographic-based information system. Initially, the data sources may be maps: eventually, considerations should be given to adopting a computer operated manipulation system in which optimum uses of land may be prescribed.

5. Continue and expand the training of analysts and other technicians via a series of workshop/training programs. Some of this could be done in the United States: some could be accomplished through a technology transfer process in Costa Rica.

2.0 IMPACT OF GROWTH AND DEVELOPMENT ON THE LAND RESOURCE BASE IN COSTA RICA

Costa Rica is experiencing a period of rapid growth and development which is having a profound impact on the agricultural and forest land base.

In Costa Rica, as in many countries throughout the world, the most intense urbanization often occurs on land that is highly productive for agricultural uses. The expansion of the urban area into highly productive agricultural land may have a significant impact on Costa Rica because the most important exports are agricultural products.

The forest resource land base is undergoing a steady decline as an alarming amount of forests, especially on steep slopes, are being cleared to accommodate more agriculture and grazing uses. In this case, the short term benefits of providing more land for marginally productive agricultural and grazing uses are far outweighed by the long term consequences resulting from the loss of mature forests and subsequent erosion and sedimentation problems.

A brief discussion of the forest resource and urban expansion will follow in sections 2.1 and 2.2, respectively. Section 2.3 provides some rationale for conducting a resources assessment program through the application of remote sensing techniques.

2.1 Costa Rica's Forest Resource and Potential for Future Management

Costa Rica has been endowed with a great natural variety of vegetation as a product of primary diverse geographical and climatic influences. The forests are distributed over four altitudinal belts, between 3,200 meters and sea level. The majority of the forests occur in areas with rainfall of 200 millimeters or more and have a profusion of epiphytes, such as bromeliads and orchids, with ferns at higher elevations and palms on the lowlands.

The forests in areas of lower rainfall have a dry season of five to seven months and are largely composed of deciduous or semi-deciduous species. Most of the remaining contiguous forest is in the north and east Caribbean lowlands, the Peninsula de Osa, on the highlands of the Cordillera de Tilaran, Guanacaste, Central, and Talamanca, and other scattered and small isolated tracts interspersed among agricultural lands throughout the country. Selective logging of the more valuable timber species has occurred within most of the accessible portion of these forests. The remaining forests have avoided complete exploitation only because of the low population densities in surrounding areas, the high density and mixed composition of the forests, and their relative inaccessibility due to the absence of passable roads, rough topography, and excessively wet conditions. Most of the marginal forest lands adjacent to the major agricultural areas have been cleared and converted to low productivity agricultural and grazing uses. The timber removed from these areas are often not marketed; however, wide use is made of fuelwood and charcoal.

The Forest Service in Costa Rica is a division of the Ministry of Agriculture. Their major mandate is to grant and control concessions for timber harvests within the nation's forests. The timber obtained from organized harvests is primarily utilized in house construction and, apart from sawmills, there is little development of forest industries. Wood exports which rank seventh on the order of importance in Costa Rica are exceeded by imports of this class, primarily of coniferous species from Honduras. The current rate of timber removal is estimated at 50,000 hectares per year while the reforestation rate is only about 1,000 hectares per year. At this rate of depletion, a sustainable forest resource base for Costa Rica may be lost forever unless immediate resource planning and management efforts are undertaken to reverse this trend.

With a rapidly increasing human population, it is inevitable that more forest land will be converted to grazing and agricultural uses, and this may be desirable so long as the land involved is well suited to these uses. Unfortunately, many areas with steep slopes that should be kept in permanent forest cover are being cleared for other uses. Accelerated erosion resulting from removal of the protective forest canopy and conversion of the land to often unsuitable uses; e.g., cropping and grazing, is causing irreparable damage to the watershed and soil resources. This land could support sustainable, long term productive forests and enhance Costa Rica's economic development, provided that good forest management is applied. Proper forest management requires a more basic knowledge about the nature and quantity of the various products available and the potentialities of the important species in regard to regeneration and growth. Also many improvements are possible for transport routes, harvesting methods, and better timber utilization to prevent waste and ensure that the most appropriate uses can be derived from timber products. The first step in realizing the potential of the forests to provide both watershed protection and harvestable timber is a comprehensive forest resource assessment program. This may be best accomplished by remote sensing techniques.

2.2 Urbanization Trends in Costa Rica

The built-up area of San Jose, Costa Rica has grown rapidly in recent years both in population (from 145,000 in 1945 to 487,842 in 1973) and in area (from 1,066 hectares in 1945 to 3,963 hectares in 1973). Examination of aerial photographs taken at intervals between 1973 and the present reveals that areal expansion and penetration into the surrounding agricultural hinterland is continuing at a rapid pace. This land is generally of high quality, inherently productive, well drained, and without excessive slope.

Much of the agricultural land which has recently been converted, 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, Figure 2-1), suggesting that these areas as well are candidates for urbanization.

2.3 Rationale for a Remote Sensing Assessment Program

Remote sensing from aircraft and spacecraft platforms has gained worldwide recognition as a unique method to provide resource-related information which is often technically or economically infeasible to obtain by conventional ground methods. Carefully planned resource surveys, using satellite and/or aircraft data products coupled with statistically valid sampling designs, can provide accurate and timely information.

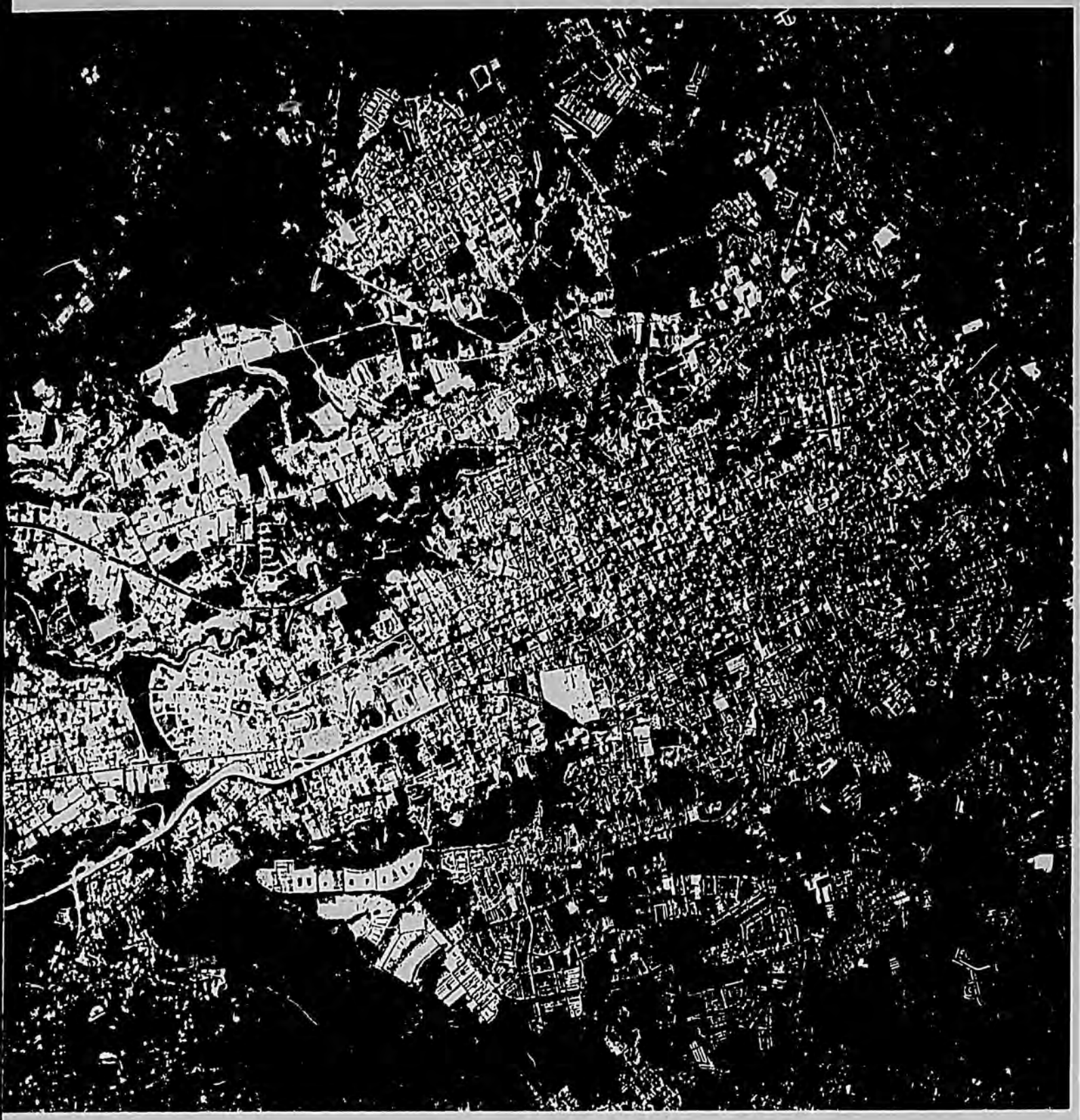


Figure 2-1
Color infrared photography of most of San Jose and its surrounding developments.

Remotely sensed data can be interpreted visually or processed by computer, displayed in map form and can be easily updated to add or integrate new data. The frequent updating of information is particularly important for planning purposes in a rapidly developing country, such as Costa Rica, to monitor critical areas of growth and change. Repetitive data generated by the LANDSAT satellite can provide timely information for regional and urban planning purposes. Information derived from satellite data can help direct the attention of planning agencies to areas where more detailed information is needed for forest, urban, or agricultural assessment programs. With this information at hand, aircraft photographic surveys may be conducted more efficiently to obtain site-specific information which can be located and verified through ground sampling techniques. Through photo interpretation and statistical techniques, this information can be extrapolated to larger homogeneous units, delineated on photographs and transferred to base maps in a more manageable form for further evaluation and decision making.

Considering the short time frame in which extensive resource data must be collected and evaluated to supply information urgently required by the Costa Rican Government for planning purposes, a resources assessment program employing remote sensing techniques may be the only feasible, cost-effective method to supply this information.

3.0 FOREST ASSESSMENT SECTOR

The intent of the forestry sector of the project was to evaluate remote sensing products and techniques by comparison of costs and effectiveness of each. Specific forest sector objectives were:

1. To evaluate the technical utility of aerial photography, including panchromatic, natural color, color infrared, and multispectral films, as well as the effects of differences in photo scale and season, for the delineation of forest cover in Costa Rica
2. To evaluate technical utility of LANDSAT satellite data, in both visual image and digital formats, for the delineation of forest cover
3. To devise a suitable forest cover classification scheme for inventory operations in Costa Rica
4. To compare relative costs and effectiveness of the various aerial photographic and satellite products and techniques
5. To conduct a demonstration in Costa Rica of the capibilities and techniques of various remote sensing systems that might be employed in a pilot program.

The overall objective of this project was to establish the relative efficiencies of these alternative systems for providing a detailed forest cover data base for Costa Rica, and then to evaluate their suitability for inclusion in a monitoring system that would update the data base at periodic intervals. Such a data base can be formatted at many different levels corresponding to different amounts of detail. Furthermore, a problem arises in comparing different products and techniques in that they yield very different levels of information. An illustration of this concept of levels of information and the resulting classification schemes is shown in Table 3-1. This classification scheme grew out of experience gained in Costa Rica during the course of this project. It is modified from Anderson's U. S. Geological Survey Professional Paper 964, which detailed a similar land-use and land-cover classification system for use with remote sensor data. Such

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

(Modified from Anderson)

1/ Additional detail for these areas can be seen in Section 4.0, Urban Sector

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

Table 3-1: LAND-COVER CLASSIFICATION LEVELS

a classification system is designed to allow interchange of information obtained by different sensor systems at different levels of detail. One notable departure from Anderson's classification is in Level I (section 3) where rangeland is subdivided into herbaceous rangeland, pasture, and brushland. Pasture in Anderson's classification is included with agriculture. During the analysis stage of this project, it was found that in Costa Rica pasture was often confused with rangeland, both in photo interpretation and in satellite data analysis. Therefore, if pasture is kept within the rangeland Level I classification, a marked increase in correct classification would result. Levels III and IV have not been fully developed in this experiment, as they are primarily designed for use in intensive forest management. The following sections of this report will evaluate each type of information gathering system independently and discuss and illustrate each type's products and usefulness.

The photography and satellite imagery were evaluated at two separate test sites; one located in the central mountains in the area of Volcan Poas, the other on the Pacific coast, south of the Rio de Tarcoles. In this report, these sites are referenced as the Poas and Tarcoles test areas. All aerial photography utilized in this evaluation was obtained by the Instituto Geografico Nacional (IGN) of Costa Rica, who also processed the panchromatic film. Processing of the color, color infrared, and multispectral film was arranged by Resources Development Associates.

3.1 Ground Surveys

Ground survey techniques are basically standard statistical techniques of inventory, with somewhat specialized inventory methods accompanying them. Modern-day forestry inventories are rarely conducted without some type of input from aerial photography or satellite imagery. This is necessary to provide a delimitation of the area that is to be sampled. In its most basic form,

information from aerial photography is usually transferred to a base map, this information primarily being the extent and location of the forest cover. The area is then determined from the base map and a number of plots allocated. The number of sample plots is usually based upon the size of the area, the intensity of the survey desired, and the confidence level of the resulting information desired. It should be noted that accurate estimation of confidence level requires some prior knowledge of the population variance.

More sophisticated use of aerial photographic information results in the stratification of the forest into different types, densities, and/or volumes. This allows samples to be allocated either directly proportional to area or to some variable trait, for instance volume. The latter results in high volume areas being sampled more intensely than low volume areas. The ultimate result of proper stratification is the lowering of the variance as compared to a non-stratified sample.

Ground survey techniques result in a myriad of different types of information depending upon what is the desired product. Primarily stand characteristics such as height, basal area of timber, species, and age are collected, with these being combined into volume tables for management purposes. Since primary costs are involved in transportation to the site and traveling time between each sampled plot, a large variety of easily measured parameters are usually obtained. This type of sampling results in a very detailed characterization of the forest. Although it is the most costly and intensive of the survey techniques, information at this level is required for intensive forest management.

This concept of using photographic products to supplement and improve ground surveys is actually extended into the use of the more advanced aerial photographic products and satellite imagery. The basic intent of both aerial and satellite information is to extend ground data, or ground truth, over a wider area with better area delimitation than would be possible otherwise. At the same time, it is possible to reduce the amount of time spent on the ground while

maintaining the same accuracy. This reduction in ground sampling effort is translated into a savings of time and money due to the inaccessibility of some areas, reduction in travel time, field time, transportation costs, and personnel costs.

3.2 Aerial Photography Technical Evaluation

The final product of an aerial photographic survey and the information derived is dependent on several variables. These variables are a variety of scale combinations resulting from flying height and focal length of the camera system, season of the year the photography was taken, and the film types and filter combinations used.

3.2.1 Mission Variables

Flying height of the aircraft and the focal length of the camera,combined,result in the scale of photography. This project evaluated what can be termed medium scale and large scale photography. Small scale photography (nominally that imaged from an aircraft at over 30,000 feet with a six-inch focal length lens) in the range of 1:60,000 scale and smaller was not evaluated. This was in keeping with the project's original intent to examine currently available systems and the fact that aircraft typically available in Costa Rica are usually limited to a flight altitude of less than 30,000 feet above mean sea level. This is not at all unusual outside of the United States.

The trade-off between scales is that as the scale grows smaller, the resolution, or what can actually be discerned on an image, is decreased. On the other hand, as scale increases, more flying time and more photography is required to cover the same ground area. It is true that a shorter focal length than the standard six-inch focal length available on most cameras could be used, resulting in smaller

scale at the same altitudes. However, such a short focal length camera usually accentuates topographic relief. In a country such as Costa Rica, where topographic extremes are commonplace, this may create more problems than it solves. All of the aircraft imagery, with the exception of the multispectral data, was flown with a conventional six-inch lens system obtaining approximate data scales of 1:20,000 and 1:40,000. Evaluation of scales can be seen in Table 3-2.

Tropic and sub-tropic multiple-season photography is much more restricted than in temperate climates. This is due to the fact that in temperate climates one can make use of the deciduous nature of many of the forests and readily distinguish deciduous versus evergreens. In tropical climates this is still a valid point, however, we are further constrained to a limited time frame by weather. The major portion of all photography flown and evaluated in this project was taken during the relatively clear months of December, January and February.

A variety of types of films were evaluated within this study. These included black and white panchromatic film, normal color film, color infrared film, and a multispectral system. Examples of each of the photographic film products are found in Figures 3-1 through 3-4. The color and color infrared photography was obtained as transparencies for interpretive purposes and reproduced as prints for this report. Transparencies are more difficult to handle in field usage, but are more effective for interpretation and were the only format available without reprinting at this time. The black and white photography was produced in a negative format and contact prints were produced. Black and white prints are useful for field work. This should not overshadow their primary use; that of providing data for a mapbase.

The black and white panchromatic film and the natural color film both record light from the visible spectrum. The use of color photographs, however, normally results in a more accurate and detailed resource assessment, as the human eye is much more sensitive

Flying Height/Scale	Evaluation of Resulting Data
Low Level/ 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 Level/ 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 Level/ 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

Table 3-2: SCALE EVALUATION

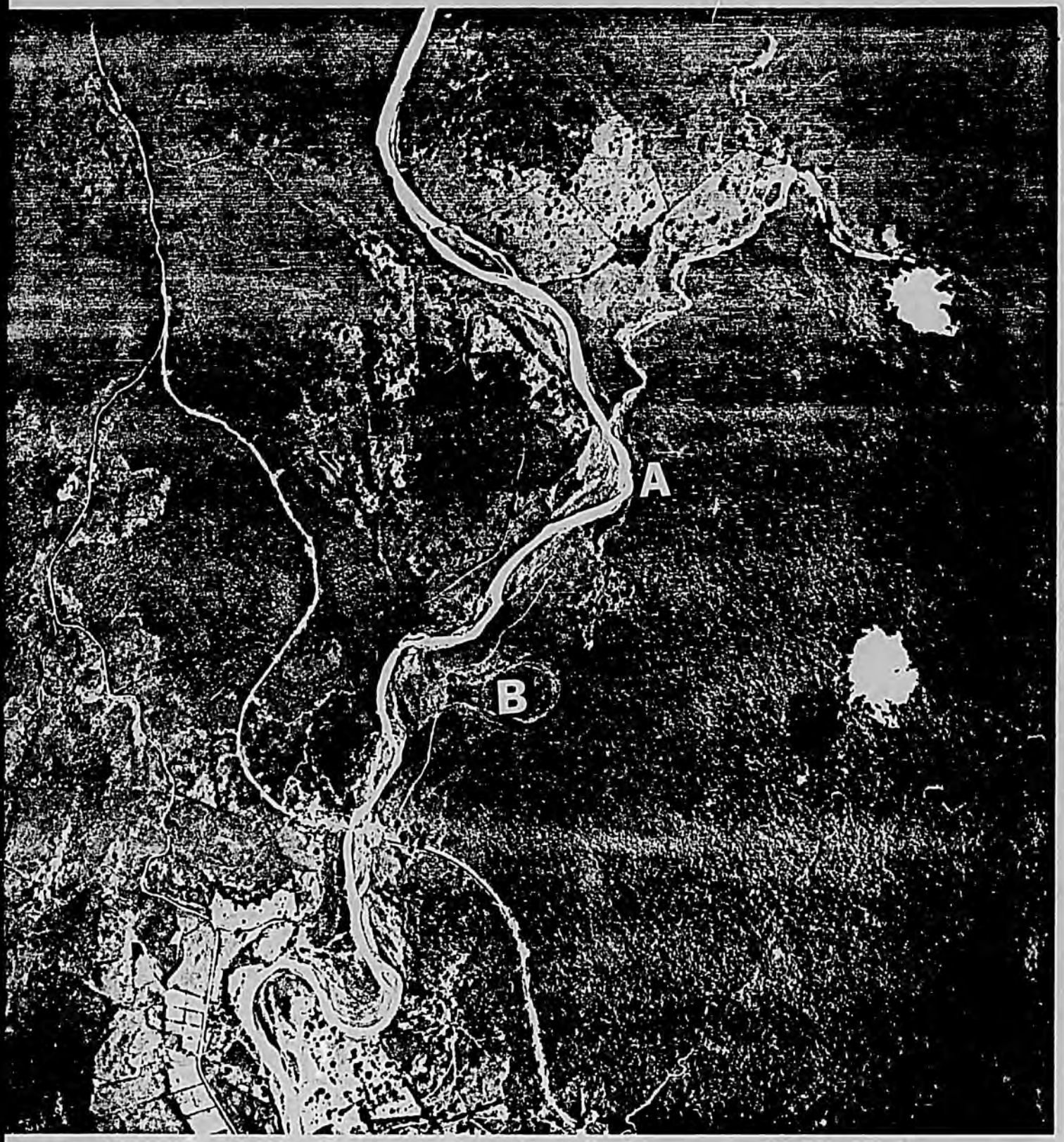


Figure 3-1
Black and white panchromatic print in the Tarcoles test area. Note points A and B for orientation and comparison of locational information with the following figures displaying various types of photography, maps and computer products of the same section along the Rio Grande de Tarcoles.

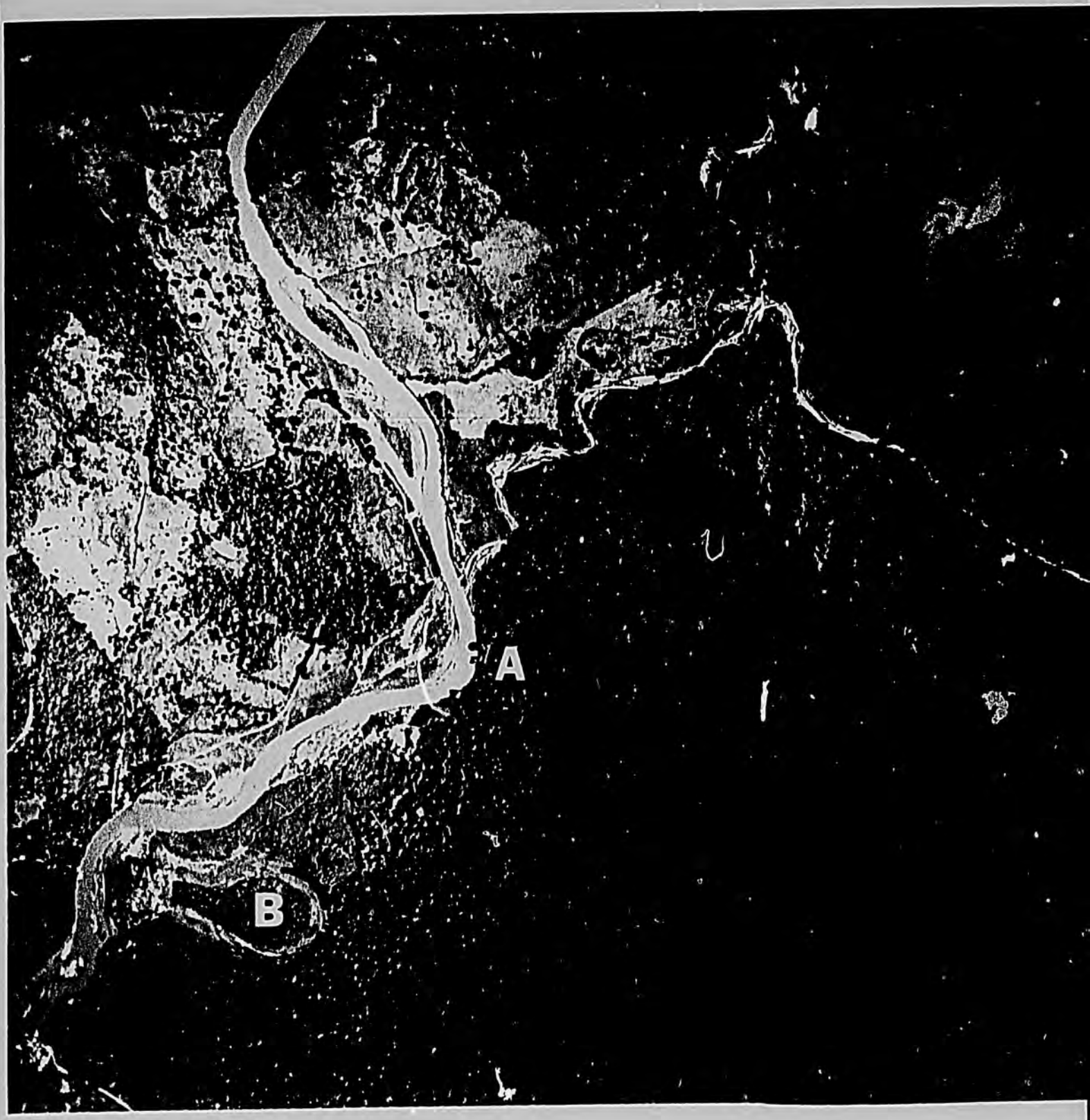


Figure 3-2
Normal color print in the Tárcoles test area at a slightly larger scale than Figure 3-1. Points A and B provide orientation for comparison of detail and information content with other figures in this report.

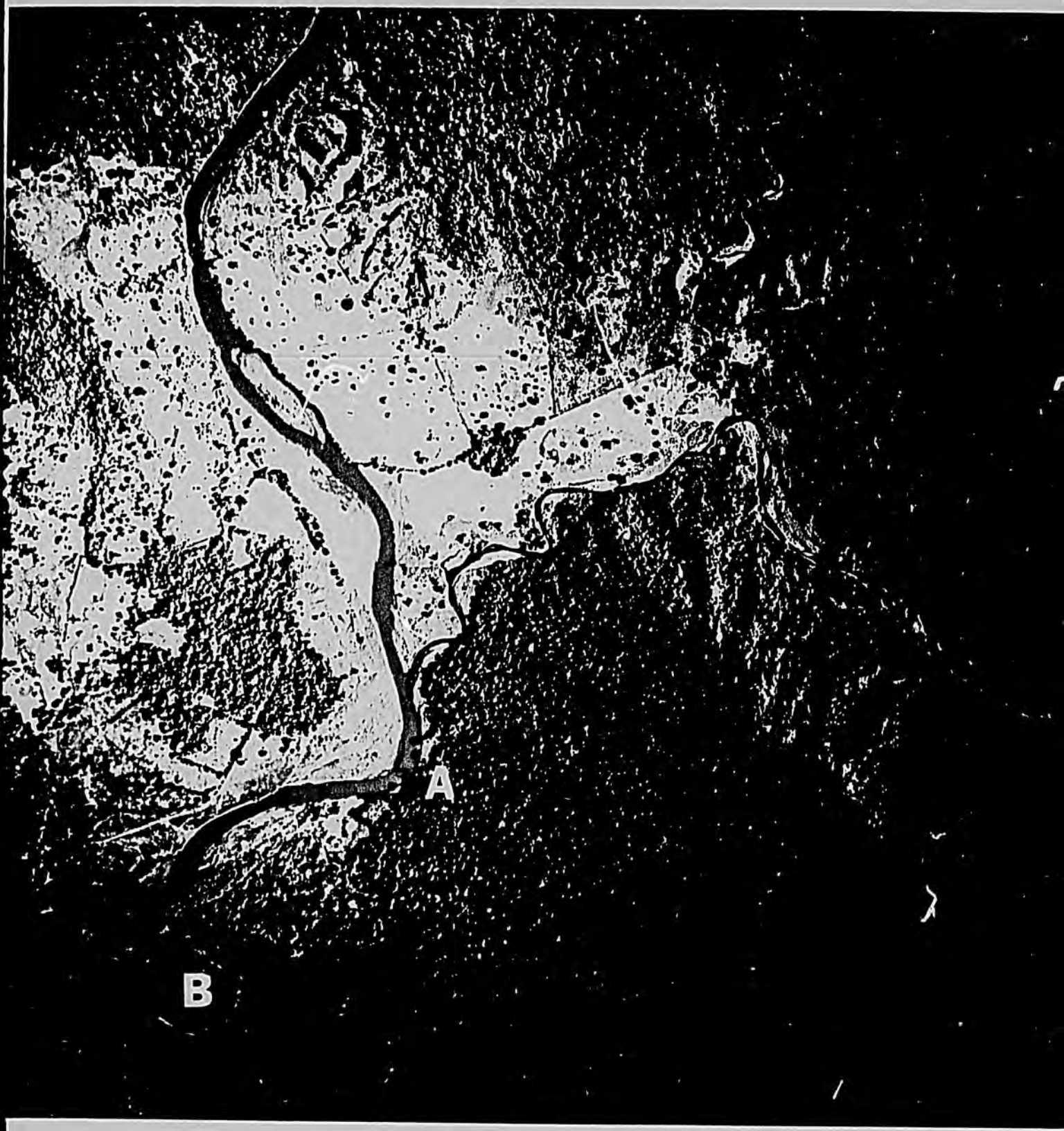


Figure 3-3
Color infrared photographic print in the Tárcoles test area. Note the location of points A and B and compare information content with Figures 3-1 and 3-2.

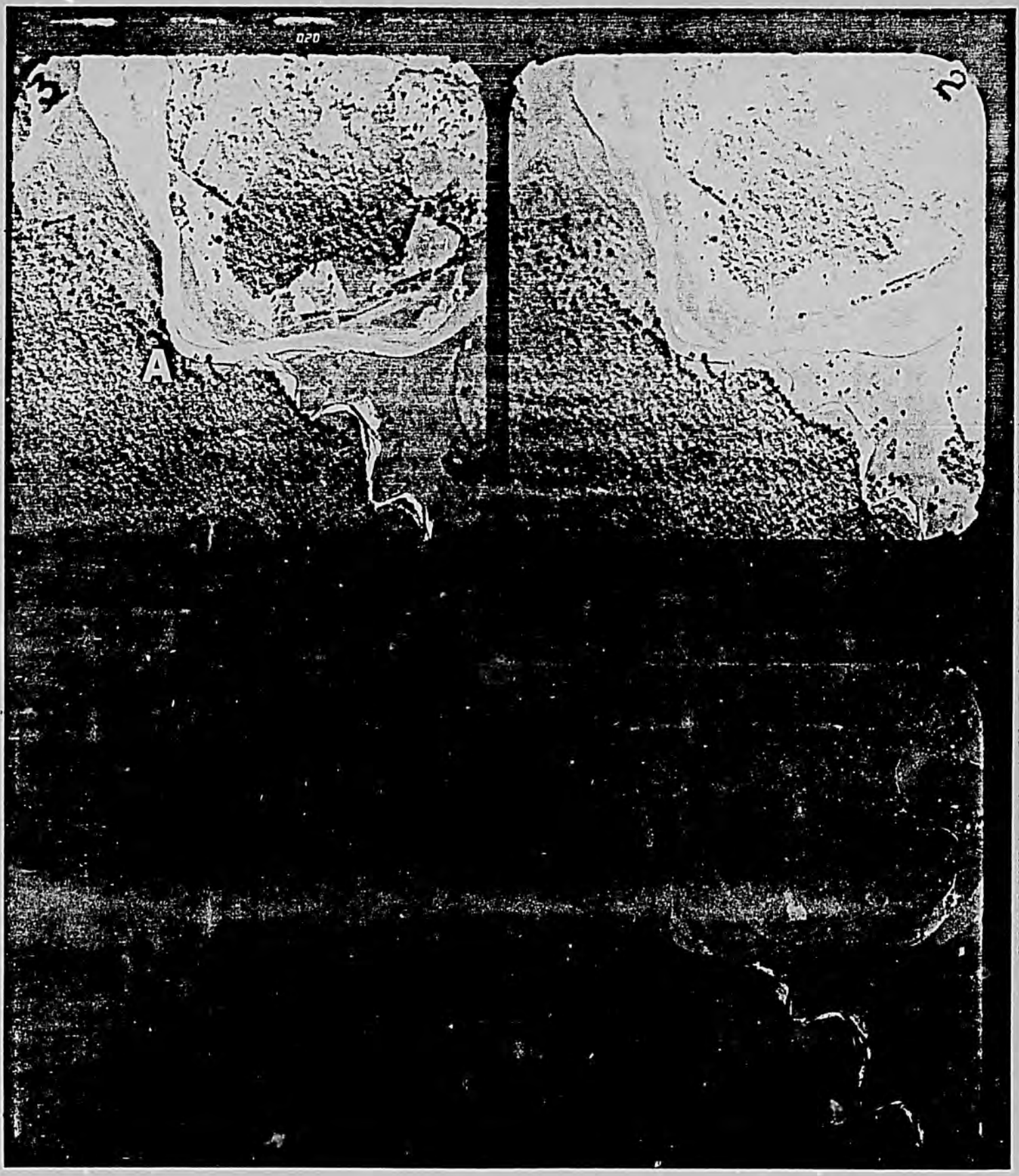


Figure 3-4
Multispectral photography of the Tárcoles test area in Bands 1, 2, and 3. Band 4 (infrared) is missing for unknown reasons. Note location of points A and B and compare information content with Figures 3-1, 3-2 and 3-3.

to slight color variations than to changes in shades of grey presented in panchromatic photos, and there are typically many more color variations than grey shades in comparable photography. Color infrared photography, on the other hand, records information in the near infrared portion of the spectrum. This is not to be confused with the thermal or heat regions of the infrared spectrum. Color infrared photographs are particularly useful for forest and vegetation assessment. Most actively growing plants have high reflectance values in the infrared, and there are wider differences between plants, and between health conditions of plants, in the infrared spectrum. Differences between dead or dying plants and living plants are also accentuated. The black and white, color and color infrared photography examined during the course of this project were all acquired with a conventional mapping camera. Differences are attributable solely to differences in film type and the fact that the infrared film requires an additional blocking filter.

The multispectral camera system requires a special camera which has four separate lenses that image on a common sheet of black and white infrared film. Each lens has a different set of blocking filters so as to record a separate and unique region of the spectrum. These regions are the blue band, the green band, the red band and the near infrared band. The four separate images are then combined using a color additive viewer with color filters assigned to each negative. The resulting combined image can be enhanced and controlled on the viewer. The multispectral imagery obtained for this project unfortunately had a malfunction in the system that prevented the infrared portion of the spectrum from being imaged. However, RDA's extensive use of multispectral photography in other areas of both the United States and Latin America shows that major problems may exist. The principal drawbacks are:

1. They cannot be used for stereoscopic viewing
2. The equipment required for viewing the material is expensive and not portable
3. The focal length of the camera dictates a large scale format.

All four of the film products and systems and their various attributes as far as interpretation accuracy and time are summarized in Table 3-3. This table details information gathered from another RDA experiment in a Latin American country. The fact that accuracy of interpretation is approximately equal for all film types tested should be noted, while at the same time the number of different units that can be differentiated is highest for color infrared photography. The average interpretation time for relatively inexperienced interpreters was best for the color. The interpretation time required for the most experienced interpreters, however, was significantly reduced when using color infrared photography.

Conclusions that can be drawn from this information, and that have been confirmed by our work in Costa Rica, are that color and color infrared films are superior materials when considering interpretation accuracy, number of units differentiated, and interpretation time.

The imagery format, as mentioned earlier, consisted of contact prints for the black and white photography and transparencies for the natural color and color infrared photography. Use of color and color infrared photography usually necessitates the use of transparencies as this is the most inexpensive and easiest way to obtain this type of film. This in turn requires the use of light tables and other such instruments that are specifically formated for a back-lighting situation. These include modified vertical sketchmasters and zoom transfer scopes. Both of these types of equipment are available within Costa Rica and should pose no problem. One of the traditional uses for aerial photography is as a map for the field technician to use in finding roads and locating where he is in relation to the forest. This is sometimes considered a major problem with transparencies, as they are not easily utilized in the field. Their information content, however, is great enough to warrant their consideration. Portable light tables can be constructed to allow one to carry his imagery, at least in a vehicle, to the field.

Land Cover/Land Use	B/W Pan (1:20,000)	Color (1:20,000)	Color Infrared (1:20,000)	Multi spectral (1:10,000)
Interpretation Accuracy	82%	82%	82%	71%*
Number of Units Differentiated	7	9	10	9*
Interpretation Time (Minutes)	25	14	16	15**
Interpretation Time (Average of Most Experienced Interpreters) (Minutes)	28	18	10	6**

* Corrected for scale

** Uncorrected for scale

Note that while unit interpretation accuracy is approximately equal for all film types tested, more units are identified with color, color infrared and multispectral films than with panchromatic film. Overall interpretation is thus most "accurate" with color infrared film.

Table 3-3: LAND-COVER/LAND-USE INTERPRETATION TESTS (LEVEL II AND III)

3.2.2 Products

After the information is collected and interpreted the next major step is transfer to a base map. In any program such as this, determination of desired final map scale should be one of the first considerations. This allows one to obtain his photography at a scale that is easily convertible, and to establish a mapping unit that is compatible with the base map. For instance, a one-half hectare minimum mapping unit would be too detailed and time consuming if the final map format were to be 1:200,000 scale; a minimum mapping unit of five to ten hectares might be more appropriate here. Conversely, a minimum map scale of five to ten hectares would be very expensive to produce compared to information content. With these considerations in mind, one can plan on using Level I and sometimes Level II classifications levels for maps at the scale of 1:500,000 to 1:200,000. Levels III and IV should be at 1:50,000 or less. In the forest experiment, map products were produced primarily at 1:50,000 scale. Data was mapped using an early classification scheme that differs somewhat at Level II and III from that presented as final. This information was then transferred via vertical sketchmasters and zoom transfer scopes to a 1:50,000 Costa Rican map base. Details of map reproduction processes used are further detailed in Section 4.0. Examples of the map products are found in Figures 3-5, 3-6, and 3-7.

3.3 Satellite Data Evaluation

The satellite data used in this experiment was obtained by the LANDSAT-2 system on March 3, 1975. A copy of this image is included as Figure 3-15. Although clouds obscure a majority of the northeastern portion of the frame, the Tarcoles and Poas test areas are relatively free of clouds. The National Aeronautics and Space Administration (NASA) did supply additional data during the summer of 1977. However, due to a limited amount of tape recording

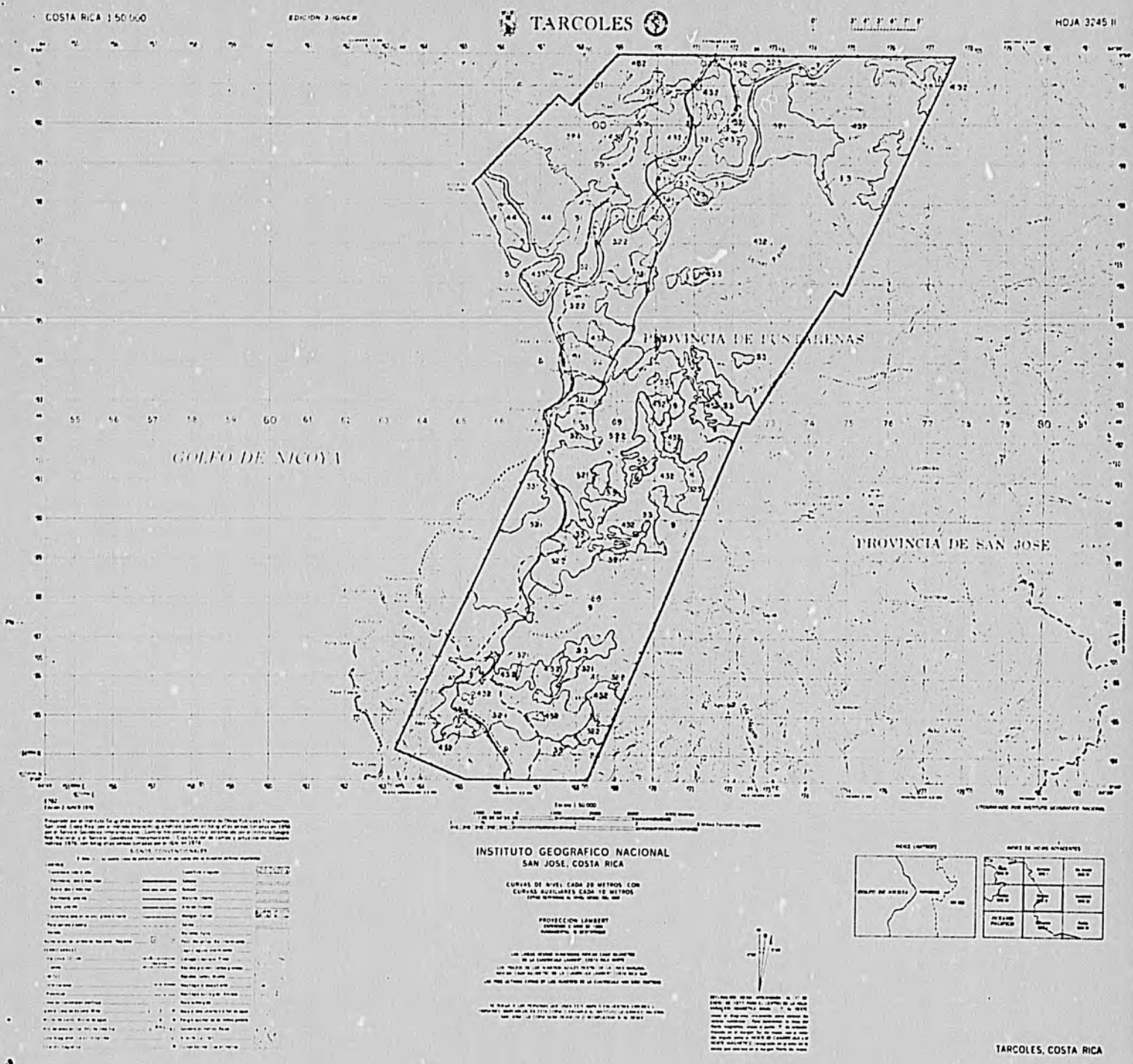


Figure 3-5
Black and white print of reduced 1:50,000 topographic map (Tarcoles test area) with land-use classification overlay. Note the location of points A and B for orientation with other figures in this report.

Figure 3-6
Black and white print at one-to-one reproduction of 1:50,000 topographic map (Tárcoles test area) with land-use classification overlay. Note points A and B for orientation with previous figures.

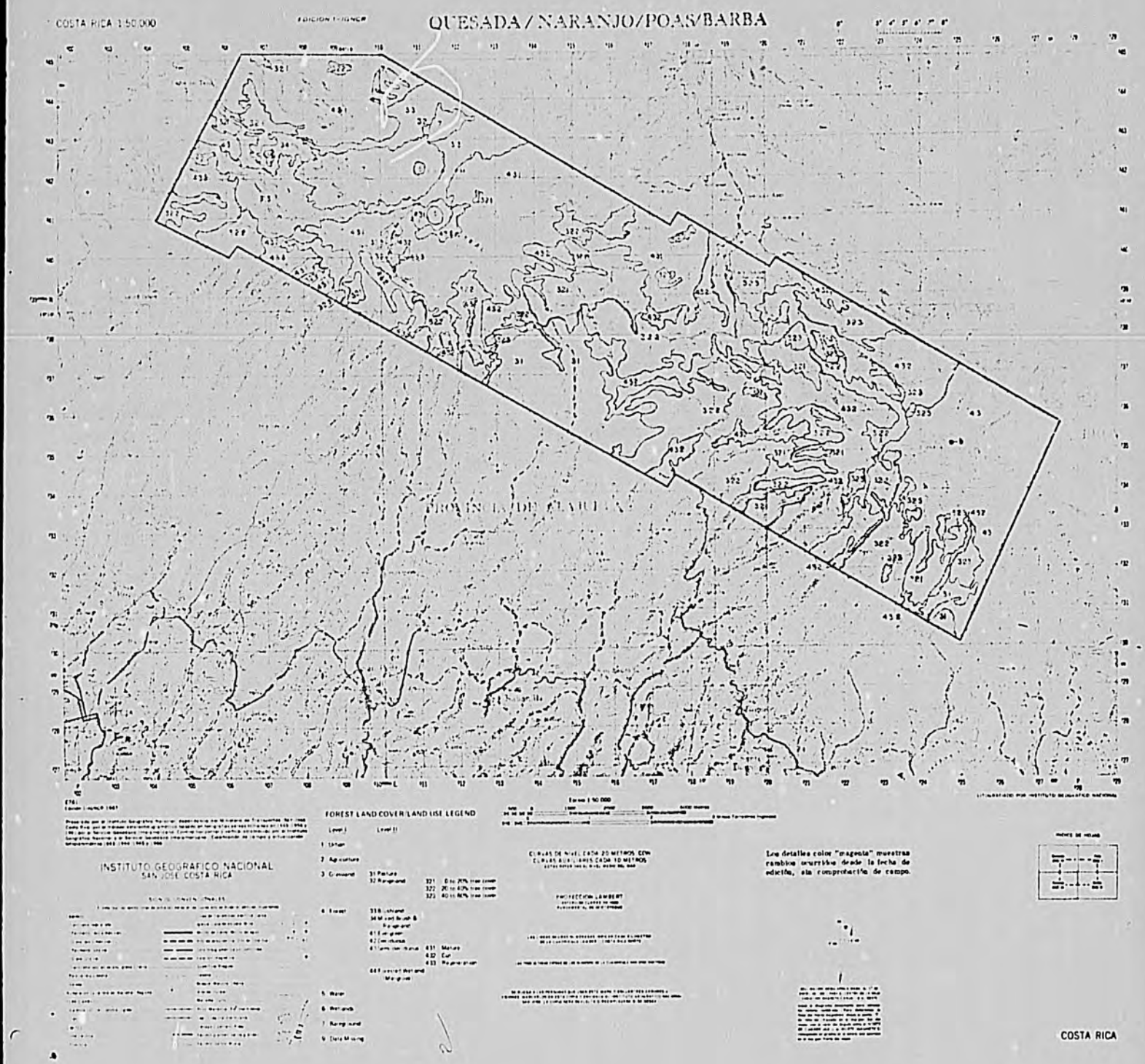


Figure 3-7
Black and white print of reduced 1:50,000 topographic map (Poas test area) with land-use classification overlay.

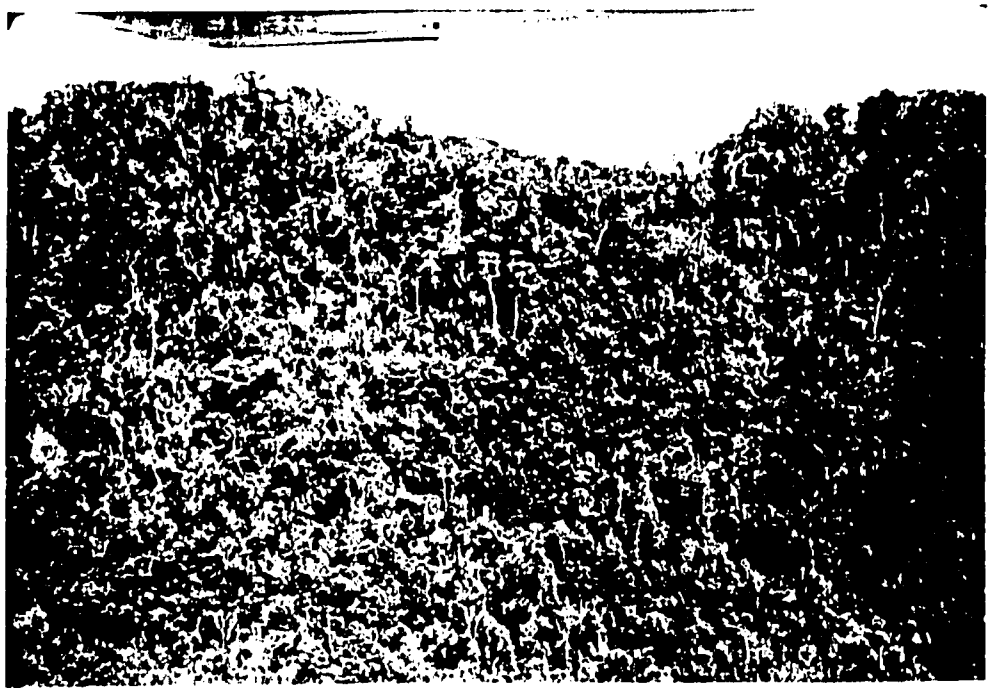


Figure 3-8
Ground-based color photograph of tropical moist forest showing cut-over forest in foreground and virgin forest in background.

Figure 3-9
Ground-based color photograph showing cross section of virgin tropical moist forest.

Figure 3-10
Ground-based color photograph in a section of the Tárcoles test area showing intermixed forest and pastureland.

Figure 3-11
Ground-based color photograph of an area near the Tárcoles test area showing a new road cut through rangeland and virgin forest.

Figure 3-12
Color photograph taken at roadside showing intermixed pastureland (foreground and background) with scattered palms and other shade trees and an agricultural field in the right midground.

Figure 3-13
Color photograph taken from roadside showing a hillside across the canyon with coffee plantations on lower and midslope, and intermixed pasture and forest from midslope to ridge top.

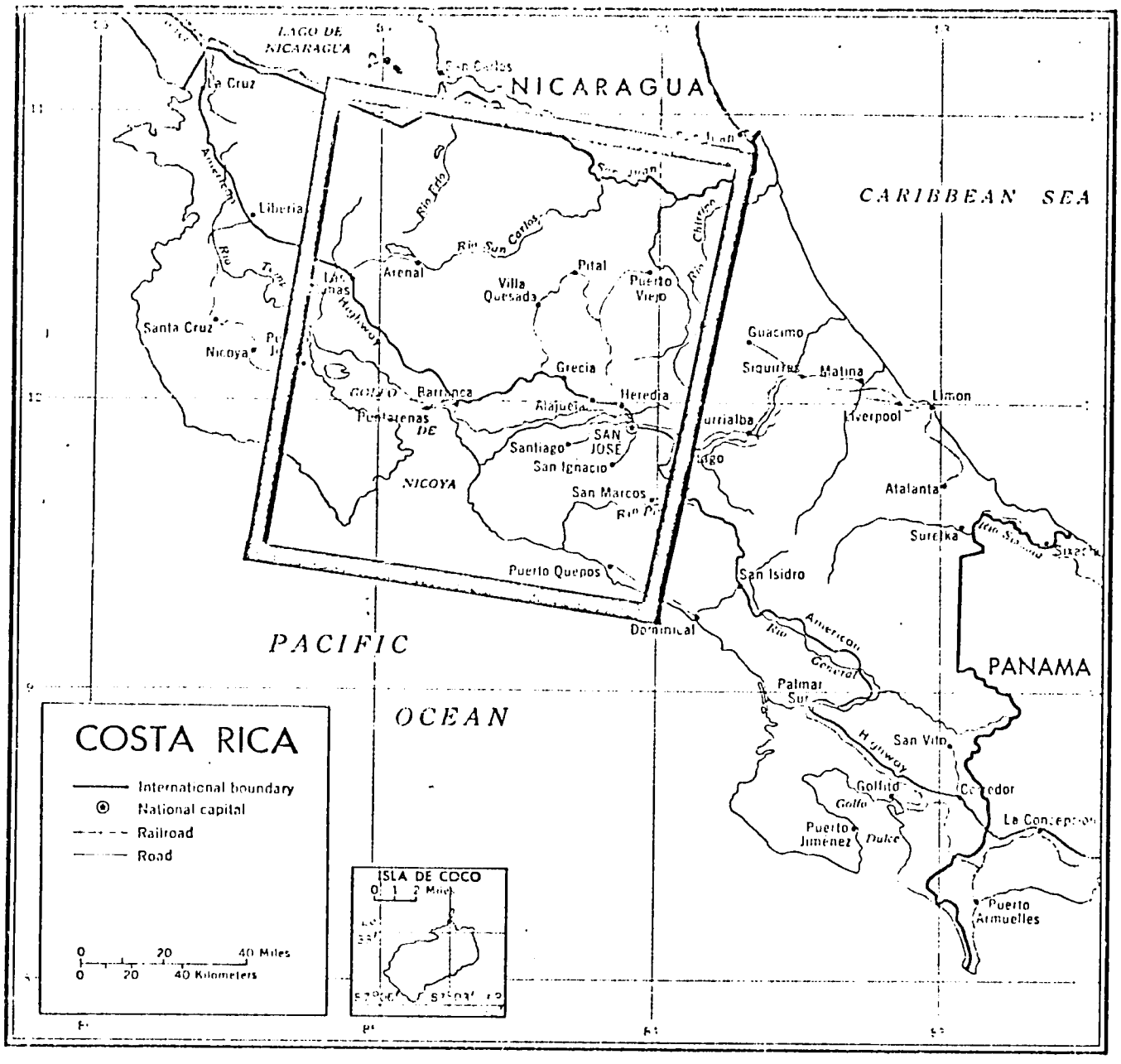


Figure 3-14
Small-scale map of Costa Rica (in white) showing the area covered by the LANDSAT frame (Figure 3-15) within the red border.

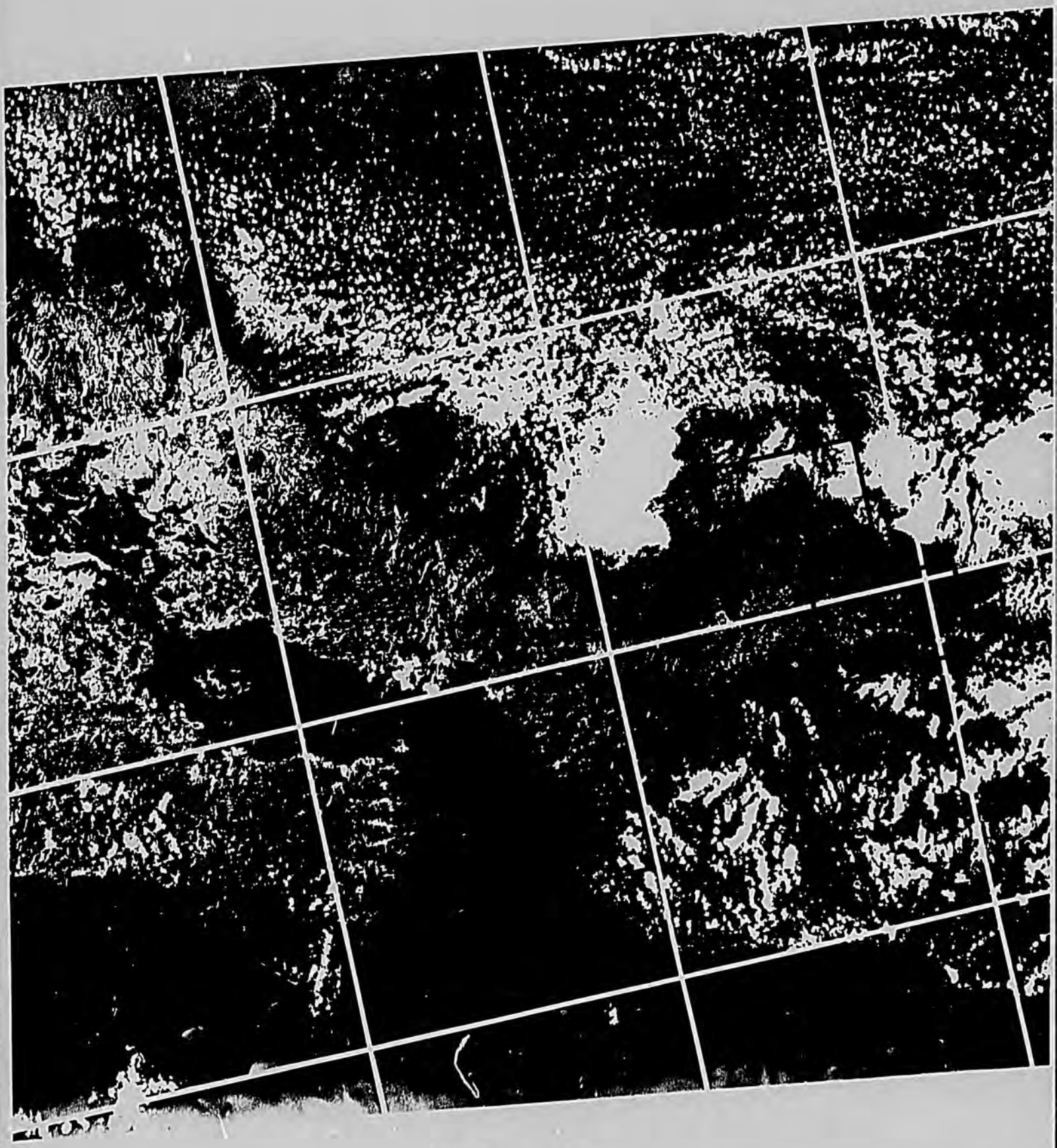


Figure 3-15
Additive color composite of a LANDSAT frame showing white latitude and longitude lines and three test areas bordered in blue: Poas, upper right center; San Jose metropolitan area, right center; and Tárcoles, lower center. Also note Figure 3-23.

space on the satellite (this being required to obtain data over areas that do not have a ground receiving station) and the onset of the rainy season, which meant that a majority of the country was under cloud cover, additional data of the quality needed to conduct such a test was not obtained. Figure 3-16 shows the best image received from this attempt, imaged on August 1, 1977.

The August image did point up some interesting and pertinent facts. If the image from the month of August is compared with the image from the month of March, it will be seen that the August image is presented in much deeper and much more extensive tones of red. Especially around the Tarcoles test area, where the forest is easily discriminated from the rangelands on the March image, there is only a very subtle difference on the August image. This is due to the fact that the March image was obtained at the end of the dry season, which meant that the rangelands and grasslands and most of the agricultural lands were in a state of plant dorminancy and dryness. The forest on the other hand had retained much of its green leaf cover and therefore stood out strikingly against the otherwise brown rangeland, agricultural land and brushland. The August image, on the other hand, was obtained after three to four months of rainfall and as a result not only the forest, but all the other lands, had a very luxurious cover of plant growth. The same differentiation that is seen by the eye was also apparent in a computer classification of these data. This confirms that not only will data be most easily obtained from the satellite during the dry season, but also that more accurate interpretations will be possible with these data.

The problems encountered with cloud cover point up another area that should be considered when evaluating satellite imagery for use in Costa Rica. It has been shown that some data can be collected over Costa Rica, but the timing of this data remains to be documented. Assuming different levels of effort from satellites; i.e., one satellite, two satellites, or three satellites, how often can one expect to obtain cloud-free coverage of the country? This will eventually be important, not only in the determination of

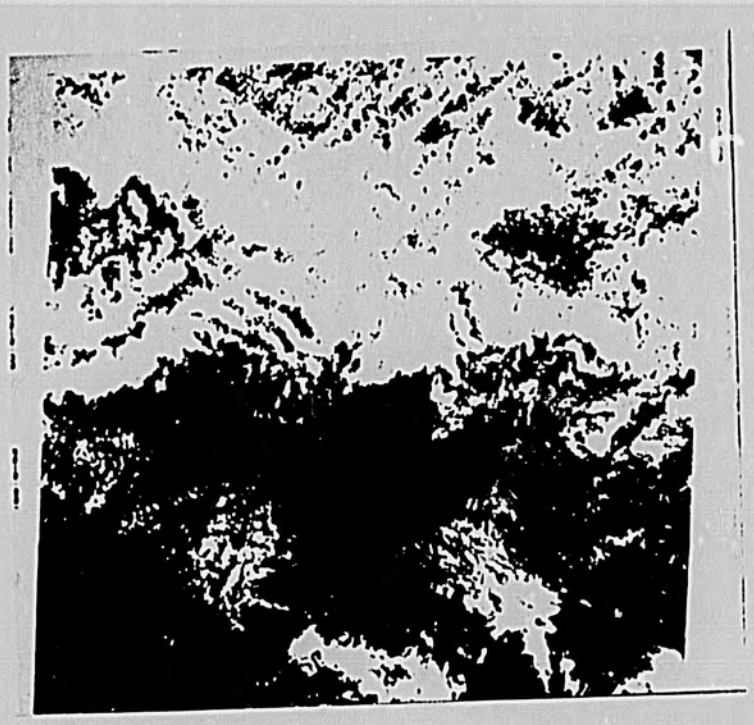


Figure 3-16
Reduction of a additive color composite LANDSAT frame taken during the wet season, with heavy cloud cover. Notice the striking difference in the amount of green vegetation (red in this Figure) compared to the dry pasture and rangeland (brown) in Figure 3-15.

the total utility of the satellite system, but also in determining its function in a monitoring system. Although beyond the scope of this demonstration project, data from some type of continuously operating and relatively inexpensive satellite system, such as the Nimbus or other weather satellite, would be examined to establish the probability of obtaining cloud-free data with the LANDSAT system in any given time frame.

3.3.1 Data Acquisition

The satellite data is transmitted as a digital bit stream from the satellite and received at a ground station, usually in the United States, and is then formattedinto a computer tape and deposited with the EROS Data Center in Sioux Falls, South Dakota. Both computer tapes and visual products produced from these tapes at the EROS Data Center were obtained for evaluation. Products examined included the 1,600 bit, nine track computer tape; 1:1,000,000 black and white images of Band 7, the infrared band; a 1:500,000 black and white print of Bands 5 and 7, the red band and infrared band, respectively; and 1:500,000 and 1:250,000 scale color composites. Also, 70 mm positive and negative transparencies were obtained. The negatives were used to produce 1:200,000 scale (matching the country map scale) black and white prints for visual evaluation and the positive transparencies were used in the International Imaging System (I^2S) color additive viewer. The I^2S product was evaluated both while on the machine and from a subsequently produced 1:500,000 color composite print.

3.3.2 Visual LANDSAT Evaluation

For the visual evaluation of the LANDSAT imagery, all four scales of the black and white products and both scales of the color products were examined, and delineations of forest cover were attempted by hand. Accurate and meaningful delineations at 1:1,000,000 were

virtually impossible, although this scale is very useful for geologic, hydrologic, and physiographic mapping. The 1:500,000 scale proved to be little better in providing mapable information. The 1:250,000 and 1:200,000 scale imagery did permit large homogeneous areas of forest to be broken out. However, at these scales it was readily apparent that any meaningful forest cover mapping on a nation wide basis would be nearly impossible. Figures 3-17 and 3-18 show enlargements of each test area in which certain units are visible at Level I. When these data were compared with both aerial photographic and digital LANDSAT data, the inaccuracy of the visual evaluations was apparent. This was especially obvious in the Poas test area where coffee, cane, and rangeland were more easily confused with forest.

3.3.3 Digital LANDSAT Evaluation

The digital LANDSAT data consists of recordings of the amount of energy that is reflected from the earth's surface in each of four spectral bands. The information for these four bands, green, red, near infrared and far infrared spectral regions, is gathered over a one-half hectare area on the earth's surface. Reflected energy within these bands is received from this area of land, called a pixel, and is averaged within each band. It is these energy levels, plus locational information, that is recorded on the digital tape. The fact that this information represents an average for a given area should be stressed; pixels that fall in non-homogeneous areas (as at the boundary of two fields) may be misclassified because the averages of the two or more different cover types yield a signal that is characteristic of neither, and may well resemble some other totally different type of cover. As the LANDSAT series of satellites become more advanced, this resolution cell may well be decreased and problems of this type, although not eliminated, may be reduced.

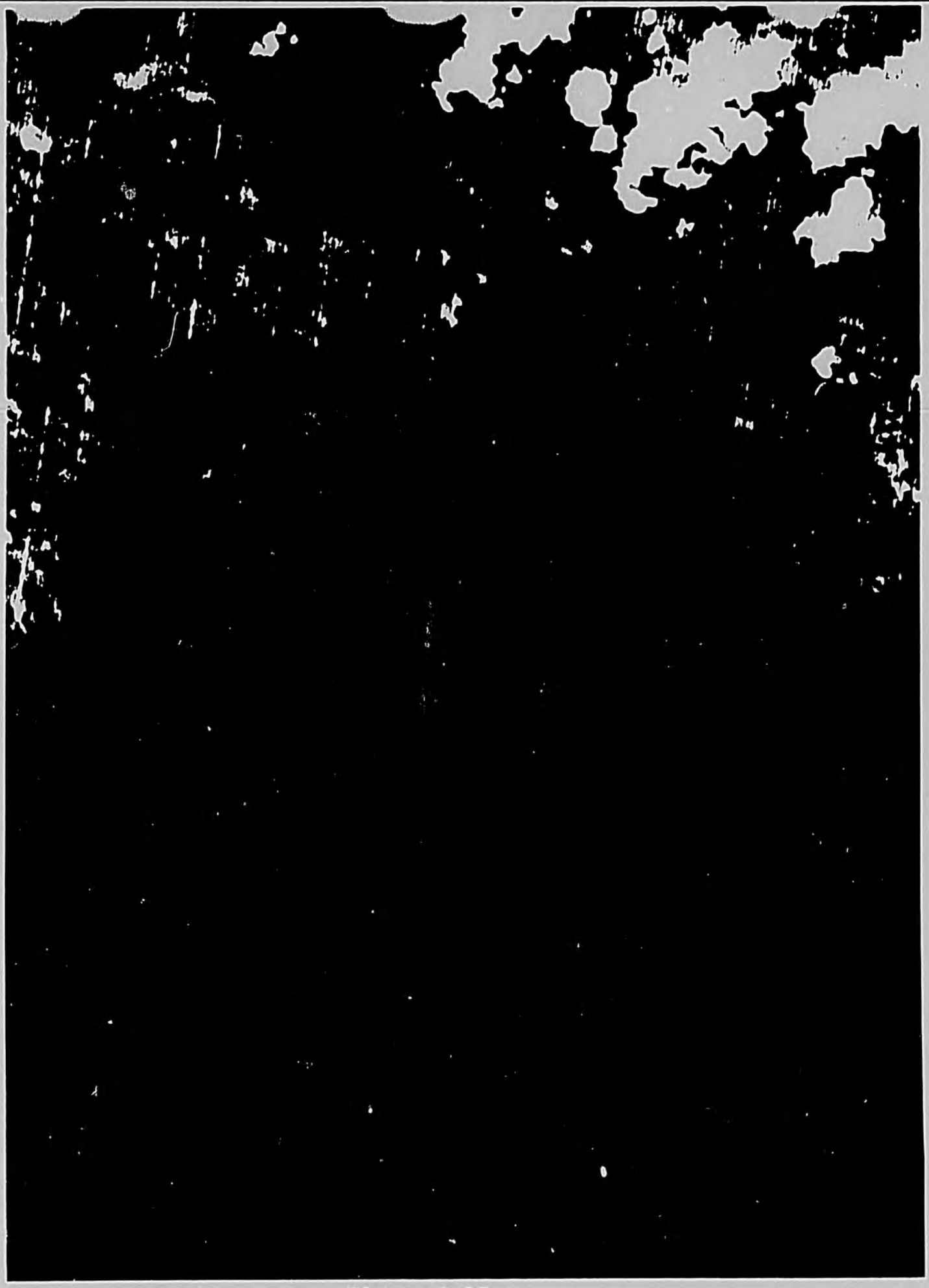


Figure 3-17
Additive color composite showing the Tárcoles test area on the Pacific coastline south of the Golfo de Nicoya.

Figure 3-18
Additive color composite of a LANDSAT frame (Poas test area). Blue area, barren volcano; white areas, clouds; dark lines trending NE to SW (center) are drainages between steep forested slopes (red).

The analysis system that was used for this project was the Electromagnetic Systems Laboratories (ESL) IDIMS system. The information from the tape was transferred into a special HP3000 computer with an interactive console. A visual display was generated on a CRT screen which had an interactive mode. Training classes were chosen visually with the help of aerial photography over each of the test areas. These training areas represented what is termed a "supervised" classification. In a supervised classification, areas that are known to be fairly homogeneous are designated and identified. The computer is then instructed to classify all of the pixels within a given scene according to the training classes generated. The IDIMS system uses a maximum likelihood classification that assigns every pixel to a class within certain statistical bounds. An obvious hazard of this type of training is that the operator may fail to identify some of the important classes, or all of the variations within each class.

An unsupervised training approach was also used for these same areas. In this process, the computer is instructed to choose random samples amounting to a given percentage; i.e., 10%, of the total image. These randomly selected groups of pixels are then analyzed by the computer system using an algorithm that allows it to generate classes of spectral responses or signatures internally. The disadvantages of an unsupervised training scheme are that one may fail to get all pertinent classes represented through the sampling technique, and some time is required to accurately identify what the classes represent.

Both the supervised and unsupervised training groups were then compared using a program that detected statistical differences between the means and standard deviations of each class generated. Any class that too closely resembled another class was re-examined and reformated. This could result in the discarding of either one or both classes, resulting in the pixels that were included in that class falling into another class. Examples of the training information, spectral signatures, and graphics of classes are presented in Appendix A.

After the training was completed, the areas were classified on an IBM 370 computer. The training took place on areas substantially larger than each of the test areas so that a real-life situation involving a great variety of pixels and responses would be obtained. If only a small window of LANDSAT data is analyzed one can, through extensive algorithms and time, very carefully refine the classification for that area. However, these classifications invariably decrease in their accuracy when extended over any reasonably large area of the frame. The classes that resulted from the training correspond to Table 3-4's Level I.

After classification on the IBM 370 computer, the data was examined as it was printed on a standard line printer typewriter. This allowed the RDA team to evaluate the training and classification of both test areas. The Tarcoles test area was judged to be an adequate representation of the efficiency of the system. However, the Poas test area fell much below expectations and was substantially less accurate than the Tarcoles classification. A re-classification was subsequently conducted on the Poas area and accuracy was improved, although not appreciably. The inaccuracies can be primarily attributed to the fact that in the higher elevations the coffee and rangeland and their growth characteristics (due to being in a more moist situation) are such that higher levels of confusion with the forest occur, and the fact that there are many shadows due to topography which meant not only the blanking out of data in many areas, but also confusion around the edges of these areas in classification. Although not a primary intent of this program, it was noted that the classification of agriculture and range in the Poas test area was very poor. This can be attributed in part to the fact that the intent of this project was not to evaluate the efficiency of LANDSAT in agricultural determinations but rather the determinations of forest versus other uses. Thus, training samples were not selected and algorithms were not chosen to maximize enhancement between agriculture and range. However, the size of the fields in different uses and the relative complexity of signals played no small part in the poor classification of the range and agricultural areas.

Satellite Mapping Legend		Forest Land Cover/Land Use Legend		
Symbol	Color	Level I	Level II	Level III
=		1 Urban		
A		2 Agriculture		
. (period)		3 Grassland	31 Pasture	
. (period)			32 Rangeland	321 0 - 20% tree cover
				322 30 - 40% tree cover
				323 40 - 60% tree cover
/			33 Brushland	
			34 Mixed Brush and Rangeland*	
W		4 Forest	41 Evergreen	
			42 Deciduous	
			43 Semi-Deciduous	431 Mature
				432 Cut
				433 Regeneration
			44 Forested Wet-land (Mangrove)	
0		5 Water		
		6 Wetlands*		
+		7 Bareground		
Blank		9 Data Missing**		

* No symbol

** Data missing due to clouds or shadow

Table 3-4

Preliminary classification scheme with keys for photographic and satellite mapping

A method termed "stratification" is available for the separation of a LANDSAT frame into two or more areas for training and classification. This allows the classification of areas more accurately by eliminating the extension of training classes over broadly different areas. Stratification per se was not used in this test due to the use of small and independent test areas, although in one respect this in itself was a stratification. The classification of the Tarcoles test area involved both mangrove and upland forest. Both classes were used as training areas, but when signatures of the mangrove were compared to the upland forests near the central valley, significant similarities were found. Stratification will probably be required in these areas, with concurrent increases in classification time and cost.

3.3.4 Satellite Products

A great variety of products can be generated from the digital classification of a LANDSAT scene. Primary products are illustrated in Figures 3-19 through 3-23. The most common type, and probably the first that anyone working with this type of system will see, is the line printer output shown in Figures 3-19 and 3-20. In this product, each pixel is portrayed by a type character. A uncolored line printer product is usually difficult to evaluate and understand. Grouping of the symbols and/or hand coloring of the groups of symbols using such inexpensive tools as felt tip markers results in a visually interpretative product as seen in Figures 3-19 and 3-20. If the classified data has been deskewed and rotated (rectification processes of the LANDSAT data) then this data is very nearly in map form. However, for greatest utility, this type of information should be transferred to conventional map bases as described in Section 3.2.2.

Figure 3-19
Photograph of hand-colored line printer output of the Tárcoles test area in Figure 3-16. See Figure 3-4 for legend.

Figure 3-20
Hand-colored line printer output of Poas test area. See Figure 3-4 for legend.

In addition to the line printer output, an additional product is tabular counts of pixels according to classes as shown in Figure 3-22. This information shows the number of pixels that have been accounted for in each class that has been identified. If the total area classified is known, these percentages will then relate directly to specific area measurements by class type, or calculations can be made given pixel size and number of pixels.

Another type of computer product resulting from the classification is the electrostatic grey print, illustrated in Figure 3-21. This type of machine product is not commercially available on an operational basis at this time.

Last of all, one of the most striking products of digital data obtainable is the film recorder output. The film recorder takes the classified tape and produces a series of negatives that are then combined into a single color negative which can be printed at any desired scale, as shown in Figure 3-23.

The amount of data contained in each of these products is essentially the same, however some consideration must be given to scale. The various scales are not readily available from the line printer as the size of the type symbol has to be a function of the size of the pixel. The line printer that was used for this project had type size that corresponded closely to a 1:25,000 scale map base. Therefore a one to one transfer of single symbol for each pixel represented was achieved at this scale. However, for production of line printer maps at any other scale, for instance 1:50,000, it was necessary to sample every other line and every other column of pixels. This results in only one pixel in four being represented in the display. Although it rarely affects the shape of, or statistical considerations for large areas, small areas and linear features such as rivers are often disturbed. The electrostatic grey printer and the film recorder, on the other hand, both respond to a change in scale by effectively shrinking the size of the pixel as it is represented on the product. The electrostatic grey printer product has been critized for being difficult

Figure 3-21
Electrostatic grey print of Tárcoles test area. The white clumped areas (right center) are clouds (missing data). Classes shown in levels of grey compare to Figures 3-18 and 3-19.

PIXEL COUNT TOTAL COUNTED 73,500

CLASS	COUNT	PERCENT
1	2374	3.230
2	1112	1.513
3	998	1.358
4	480	0.653
5	2258	3.072
6	1097	1.493
7	560	0.762
8	999	1.359
9	1428	1.943
10	16	0.022
11	97	0.676
12	[illegible]1	0.314
13	223	0.303
14	1195	1.626
15	2068	2.814
16	1295	1.762
17	1508	2.052
18	4456	6.063
19	2964	4.033
20	675	0.918
21	13272	18.057
22	258	0.351
23	3608	4.909
24	3684	5.012
25	8728	11.875
26	3946	5.369
27	1879	2.556
28	3098	4.215
[illegible]	2049	2.788
30	6544	8.903

Figure 3-22
LANDSAT pixel count area determination

Figure 3-23
Photograph of computer enhanced color coded image of the Tárcoles test area. See Figure 3-4 for legend.

to work with since it is portrayed in only levels of grey and the human eye is not as responsive to different levels of grey as it is to different colors. The film recorder for this reason is usually considered a more easily interpreted product since there are usually more possibilities for easily distinguished classes. Unfortunately, it is significantly more expensive than most other output product types.

3.4 Summary

A comparison of photographic to digitally processed information can be seen in the uncolored line printer output and overlay in Figure 3-24. The information on the overlay was derived from aerial photography over the same area to permit comparison of the relative accuracies of the photographic and LANDSAT digital products. Legends for the photography and line printer output can be found in Table 3-4 (page). A summary of the different remote sensing systems and their relative value for each level of classification is presented in Table 3-5.

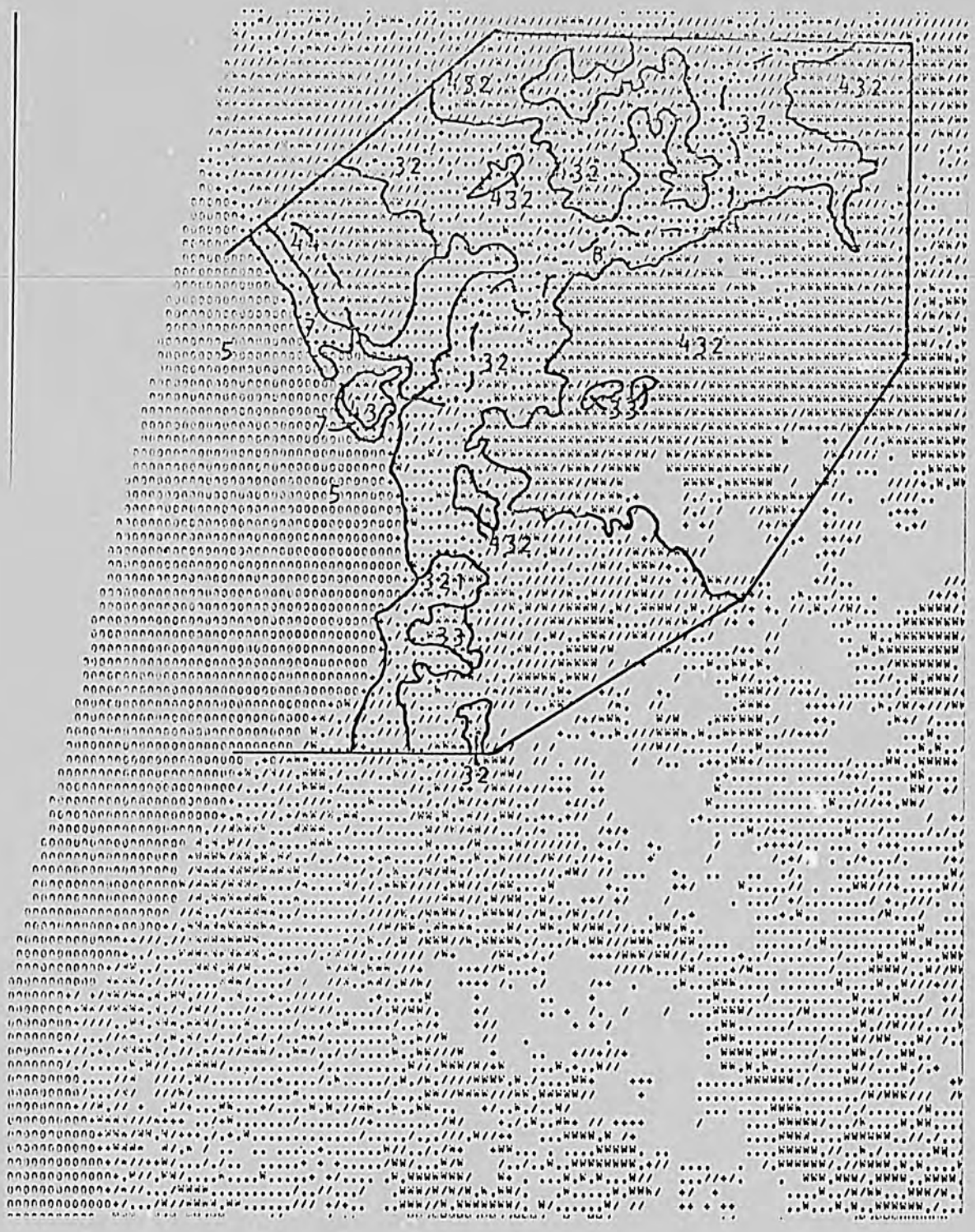


Figure 3-24
Line printer output of the Tárcoles test area; overlay shows a comparison of the photographic derived information. See Figure 3-4 for legend

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.

Table 3-5

Applicability of various remote sensing systems. This table compares the three remote sensing systems evaluated to the Levels of classification shown in Table 3-1. Details on costs are found in Section 5.0.

4.0 URBAN ASSESSMENT SECTOR

The general goals of the urban demonstration project were to examine and test the various tools and techniques which policy makers in Costa Rica could employ in the development of plans to guide the future growth of the cities in such a way that valuable agricultural land resources and desirable open space would not be lost. Carried on into the pilot program and the national program are the conceptualized goals of the development of a growth plan which identifies the quality of rural land in the cities hinterland, protects the highest quality land and directs the probable inevitable urban growth onto land whose conversion to urban uses would cause the fewest problems.

4.1 Goals

To provide the means by which these general goals can eventually be met, the specific boals of the urban segment of the Demonstration Project were:

1. To test the suitability and applicability of the data sources of:
   a. Black and white panchromatic aerial photography
   b. Natural color aerial photography
   c. Color infrared aerial photography
   d. Multispectral aerial photographys
   e. Digital data from LANDSAT satellite in computer compatible tape format processed by computers using clustering and classification algorithms
2. To adapt a variety of interpretation, mapping, and data manipulation techniques to the precise needs found in Costa Rica
3. To use aerial photo interpretation to classify and map both urban and non-urban land uses in a test area extending from the western edge of San Jose to the Coco International Airport

4. To determine the best combination of a classification system and map scale to provide the optimum amount of data in a cost-effective way
5. To delineate the boundary of the contiguously built-up area as a base from which to measure future change
6. To provide details on the stages of land-use change in the rural-urban fringe areas
7. To attempt to use LANDSAT digital data to define broad classes of land use, both urban and rural
8. To use these processed LANDSAT data as a baseline measurement from which expansion of the urban area could be measured in subsequent passes with a view toward the establishment of full-time monitoring of urban growth in the future.

4.2 Method Used with Aerial Photo Interpretation

The primary product to come out of the urban sector of the demonstration project was to design and sample mapping of the baseline data in the form of a polygonal land-use map derived from the interpretation of aerial photographs. Several basic problems were resolved, such as developed a classification scheme, determining minimum mapping units, deciding on an optimum base map scale, eveloping interpretation techniques appropriate to the area, designing a system for eventual reproduction of the maps, application of a technique for measurement of polygons, and the subsequent aggregation of these data by meaningful administrative units in order to begin the process of relating the remotely sensed data to information previously collected on the ground and reported by the census and other agencies. These and other points are taken up in detail in the following pages.

4.2.1 Land-Use Classification System Development

In consideration of the problem of how best to classify the use of the land two options exist:

1. Either inductively designing a unique system

or

2. Adapting one developed elsewhere.

Since the geography program of the U. S. Geological Survey has already designed a classification system for use specifically with remotely sensed data (Anderson, et. al., 1976), and that the system is in broad usage and widely quoted, the decision was made to use its basic structure, but modifying it to suit local requirements where necessary. A major design feature of the Anderson system allows for identifying discrete land uses as logical subdivisions of broader categories. This is a particularly attractive feature for usage in Costa Rican urban area mapping where fine detail is desirable in some areas such as the urban fringe, and is not required where uses are not subject to imminent change.

The degrees of detail are seen in Figure 4-1. Single digit uses (Level I in the Anderson system) are used in the urban areas to denote rangeland and forest land; both of these are treated in more detail in the forest sector of the project. Two digit uses appear both in the urban and in the rural. In both instances, the level of detail indicated is all that can be determined through aerial photo interpretation. For instance, commercial and services cannot, from satellite or aerial photographs, be subdivided into types of goods and services. These determinations can only be made through ground observation.

Three digit classes consist of both urban and non-urban land-use phenomena. On the urban side, the residential class is subdivided on the basis of building density. The low density areas are those associated with semi-rural areas where houses are separated by tens of meters. Middle density housing is found on the urban

Land-Use Classification System for Air Photo Interpretation Mapping

Class Number	Class
	URBAN
111	Residential (low building density)
112	Residential (medium building density)
113	Residential (high building density)
12	Commercial and services
13	Industrial
14	Transportation, communications, and utilities
15	Industrial and commercial complexes
16	Institutional
171	Recreation
1721	Coffee (viable)
1722	Other agricultural land (viable)
1731	Coffee (abandoned)
1732	Other agricultural land (abandoned)
174	Vacant land in transition

Class Number	Class
	NON-URBAN
211	Sugar Cane
212	Field Crops
213	Other (including small, fenced pastures)
221	Coffee
222	Bananas
223	Palms
224	Greenhouses
23	Agricultural Structures
3	Rangeland (grass)
4	Forest Land
51	Streams, canals
52	Lakes
53	Reservoirs
72	Beaches
74	Bare, exposed rock
75	Strip mines, quarries,

Figure 4-1

The classification system used with the mapping of urban land uses from air photo interpretation. Note that land uses of greatest concern are in three and four digits (Levels III and IV) while those of less concern are less specific.

periphery while high density housing occupies the older parts of San Jose and surrounding satellite communities where units either share common walls or have side walls which abut one another. Land devoted to recreation and vacant land in transition also require a three digit distinction. In the non-urban land, discrete crops and classes of crops require third level distinction. Not all of the uses in the system occur in the Meseta Central but will be encountered in the Pacific to Atlantic area covered by the Pilot Project.

The extension of the system to four digit detail in the case of rural-urban fringe uses was necessary to attempt to gain a level of data necessary to help resolve the problems associated with the conversion of land from rural to urban. The delineation of the status of agricultural land within the urbanized zone into viable and abandoned helps to identify not only the use of the land but also its stage in the conversion process. From such data can come an ability to predict future change and to monitor urban growth. Such information can provide the basis for policy formulation.

In summary, the classification system as modified and amplified for use in Costa Rica served the project's purposes well. All the types of land uses and land covers encountered in the test areas were covered by the classification system. Clearly, urban land uses in Costa Rica are more nearly universal than they are unique.

4.2.2 Field Observations

The universal remote sensing technique of relating sample observations, "ground truth," to interpretation of aerial photographs was successfully employed. During two separate trips to Costa Rica, one in May 1977 and one in November 1977, numerous local trips were taken by motor vehicle into the test area. Traverses along the corridor from San Jose to Naranjo were made and specific features identified which could later serve as "signatures" to be extended to other areas.

Some of these trips were taken in USAID vehicles, other with INVU colleagues. Cooperative effort in the field was extremely useful in reaching agreeable classifications for the many diverse land uses encountered.

A light airplane was also employed for field observation as well as to take a progressive series of low level oblique photographs. These pictures, taken with a 10% overlap from the aircraft window with a 35 mm camera, were used as supplements to the vertical aerial photography taken by IGN. With the lens used (a high resolution 55 mm) and at a flying height above ground of approximately 2,000 feet, the detail in the photographs was very fine and aided in a significant improvement in identification of certain land uses. As seen in Figure 4-2, the oblique view of the same area provides more information: building heights can be determined and the nature of the vehicle in the storage yard in the distance provides a clue as to the exact nature of the land use. Similar coverage was attained for two paralelling flight strips for most of the corridor between Cartago and Naranjo.

4.2.3 Aerial Photo Interpretation

Traditional methods were employed to extract land-use data from the aerial photographs. First, a matte finish piece of plastic film was mounted over the 9 x 9 inch aerial photo transparencies. Registration tabs were attached both to the photographs and to the overlay material and joined by registration pins thus insuring continuous registration. The heart of the photograph, that area with the least distortion, was then delimited; about one centimeter of overlap was allowed on each side to facilitate the joining of edges. Land uses were then identified (with the aid of optical magnification) and classified. Each polygon of use was marked and indicated with a code number. The minimum mapping unit of one hectare was generally used although some smaller polygons were delimited where they contrasted so sharply with adjacent uses that subsuming them within a

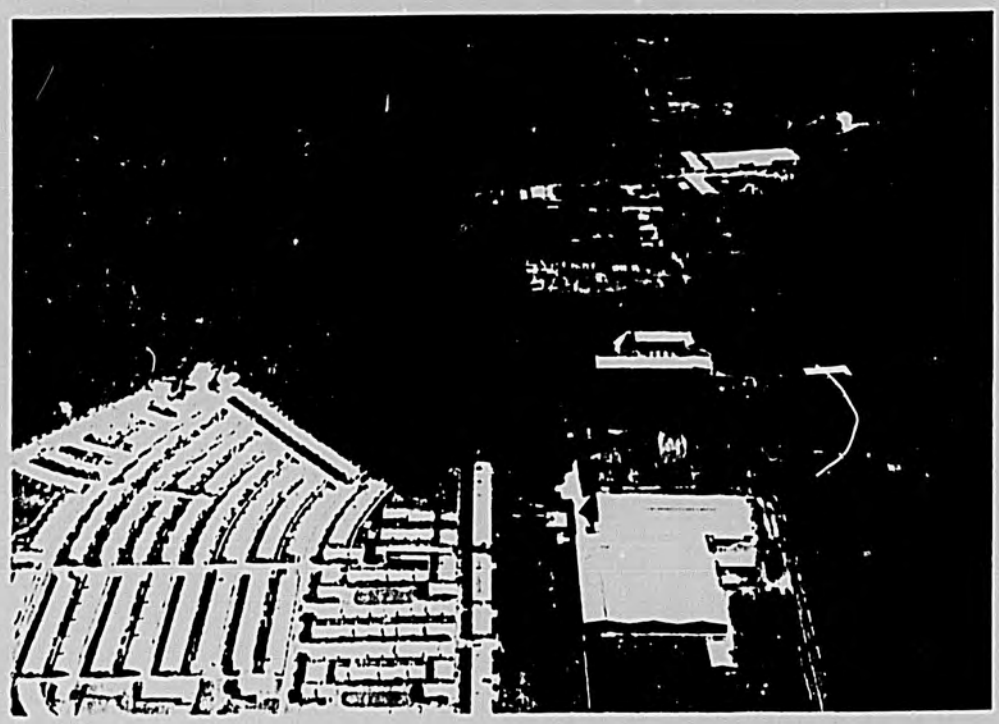


Figure 4-2
Vertical and oblique view of an INVU housing development. The ability to discern building height and the greater detail of the oblique photo view demonstrate its use as a supplement in the interpretation process.

broader class would reduce the map's integrity. Polygonal boundaries were drawn as accurately as possible and frequently contained many sharp angles where they traced streets and blocks.

A method commonly employed in the interpretation process was to mount the mapping overlay on a natural color photograph and make general interpretations with a four-power magnifying lens. For more difficult areas, reference was made to the supplementary materials of color infrared photographs (viewed in stereo on a Bausch & Lomb Zoom Stereoscope) and the previously mentioned natural color oblique photographs.

4.2.4 Map Compilation

Since the representative scale of the photographs and the base map were not identical it was necessary to match the photo overlay to the map scale. One set of photographs has a scale of approximately 1:21,000, with the second set at approximately 1:35,000; some variation also occurred along the flight lines.

The device employed to match scales was a copy camera. Matte finish mylar overlays were either enlarged or reduced (mostly the latter since the larger scale photography was predominantly used) and printed at base map scale (1:25,000) on a clear base transparent photo mechanical transfer material.

The scaled polygonal transparencies were then matched to the prepared 1:25,000 base map (in negative transparency format). All the land-use polygons were compiled onto a single sheet of matte finish mylar overlaying the entire base map sheet. Minor adjustments were made to reach compatibility with the point and line features of the map. Since the 1:25,000 base map was enlarged directly from the 1:50,000 scale standard Costa Rican series of topographic maps, apparent road widths are excessive. Polygonal boundaries were often simply placed down the middle of the road.

4.2.5 Pre-Proofing/Publication Preparation

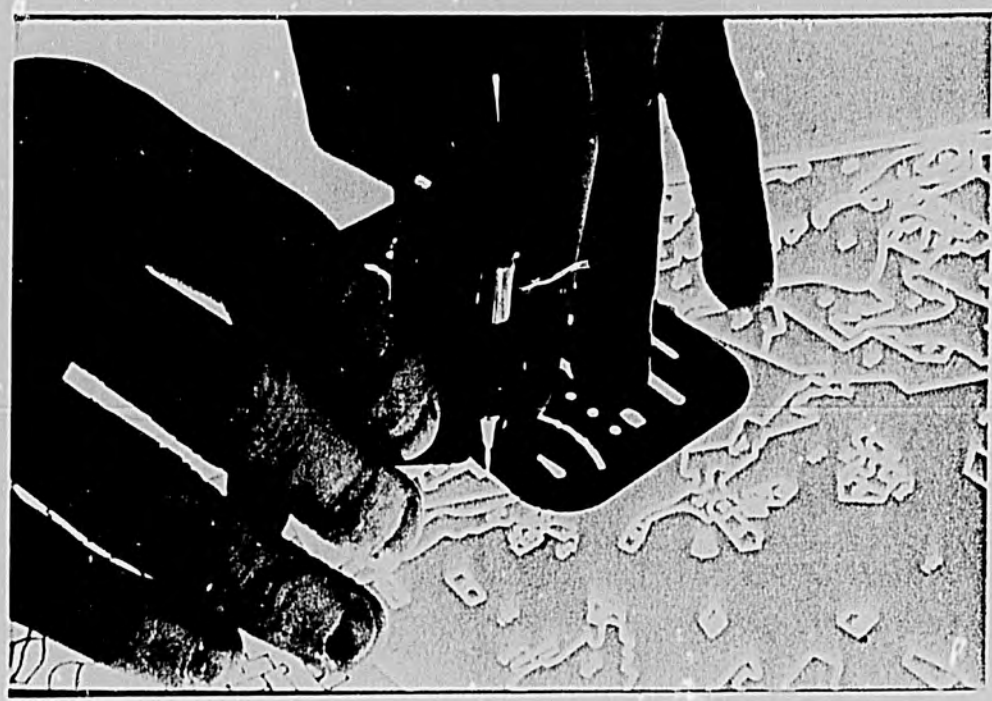
From the mylar compilation sheet a scribe guide was then prepared. Using this guide, an RDA geographer, working with a K & E rigid graver (with a .015 point) scribed all the polygonal boundaries. The top scene in Figure 4-3 shows the scribing in process. The bottom scene shows the completed scribe sheet (with the area covered by the flight line mapped) and the prepared 1:25,000 base map negative. Identifying code numbers were then scribed within polygonal boundaries.

The completed scribe sheet, always kept in perfect registration with the negative of the base map, was then proofed. The negative was first reproduced on a proof sheet of heavy duty opaque plastic material. On one of the proof sheets (Figure 4-4) the base map was reproduced in a grey tone through the use of an interposed screen (30%). The land-use polygons were then placed over the top in dense black. In the other two examples, the base map was reproduced in a shade of brown while the polygonal boundaries and numbers were in black. Either method yields a satisfactory product.

While only proof copies are seen in this report, the separation sheets (the scribe sheet and the base map negative) which resulted also have the capacity to be used directly to make plates for printing. The system used in this demonstration project is structurally identical with that used by major map producers such as the U. S. Geological Survey and the Instituto Geografico Nacional of Costa Rica. Thus, a project goal was reached of demonstrating professional reproduction methods.

4.2.6 Land-Use Area Measurements

Geographic spatial data on land use must be measured and organized by some useful units if it is to be used in planning. Thus, the area of each polygon of use must be measured and the data tabulated and ordered. The tool used for this purpose in the project was an electronic planimeter/digitizer. The instrument used, a



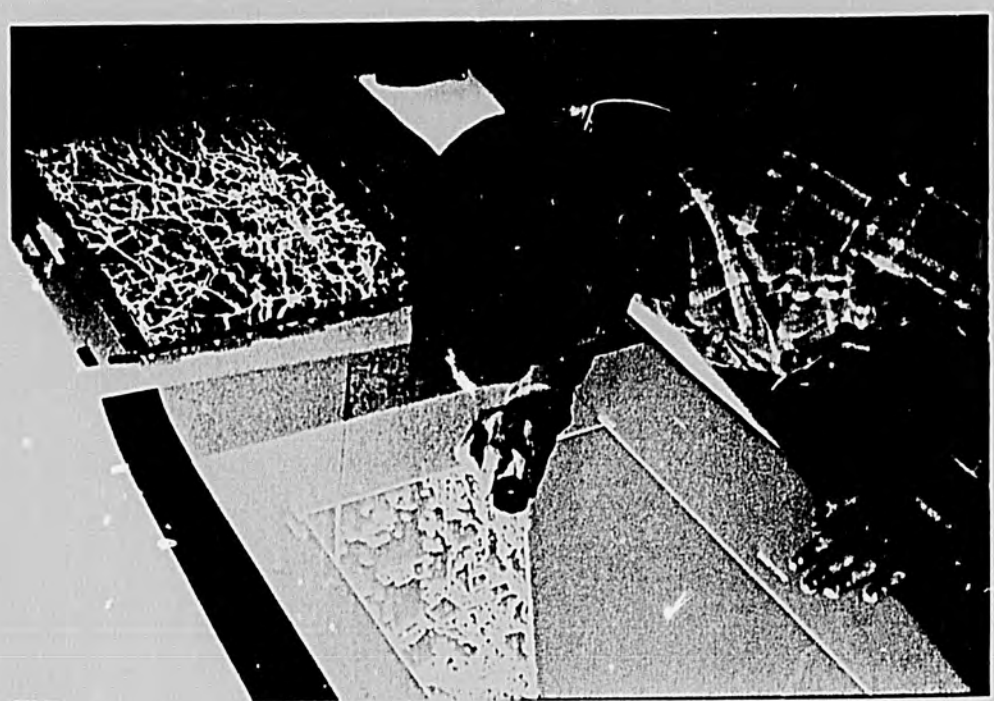


Figure 4-3
Land-use polygon scribing and the map separation sheets. In the upper picture, the method of scribing is seen: in the lower, the scribe sheet lies alongside the registered negative of the map at the 1:25,000 scale.

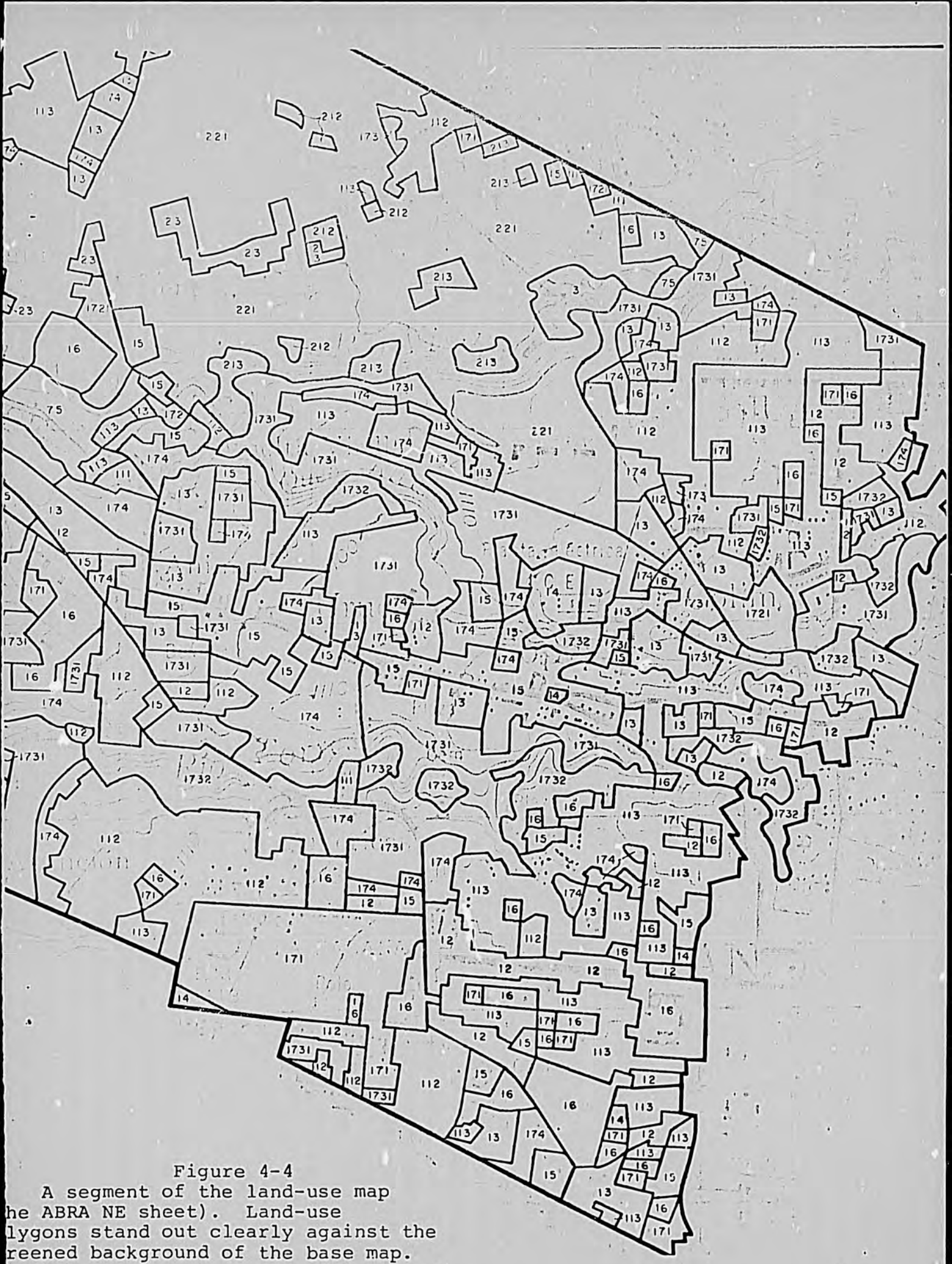


Figure 4-4
A segment of the land-use map
he ABRA NE sheet). Land-use
lygons stand out clearly against the
reened background of the base map.

Numonics 1224, is seen in Figure 4-5. The first of the scenes shows an operator directing a cursor around a land-use polygon. Movement of the arm actuates geographic x and y coordinates in the flat box at the left edge of the picture. These coordinates are then used by the computational device (the large box) to determine area. In a real case, as seen in the center picture, the perimeter of the polygon enclosing the medical complex which surrounds Hospital San Jose de Dios (classified as institutional) has just been traced by the needle pointed cursor. In the bottom photo, its area of 15.94959 hectares appears on the display screen; the function control box is seen in the foreground.

The plan in the pilot project is to measure all polygons and report their areas by administrative districts. In the demonstration project, the only entire district mapped was that of Cinco Esquinas, lying between San Jose and San Juan de Tibas. The result of this measurement is reported later when photo interpretation mapping and computer-aided digital analysis mapping are compared.

4.3 Method Used with Computer Processed Satellite Data

A goal of the demonstration project was to test the viability of using computer processing to make land-use maps from digital data transmitted from LANDSAT satellite. To this end for the urban project, a test area -- running from San Jose to Alajuela -- was selected. Of the available two LANDSAT data tapes which covered Costa Rica, one in 1975 and the other in 1977, only the earlier one was satisfactorily cloud free over San Jose. As a result, the demonstration experiment was faced with the problem of having aerial photography of a more recent date (1977) than the usable satellite data (1975); the reverse is usually true.

As is customary in working with LANDSAT data, the test site is indicated by the number of picture elements (pixels) it contains. The site selected was a modest 139 horizontal lines by 326 vertical columns. Since each pixel of 79 x 57 meters contains an area of .45

hectares, the total number of 42,054 pixels comprises an area of 18,924 hectares.

4.3.1 Clustering

The method of interpreting spectral data in digital form received from the satellite is readily subdivided into the two principal operations of clustering and classification. In the former, the four light reflectance values recorded for each picture element (four discrete grey levels on a 0 to 128 scale) are examined interactively. Combinations falling within a given standard deviation which are alike are said to "cluster" in four-dimensional space (measurement space). These "clusters" represent signatures, or are surrogates for a type of land use or land cover. These land uses or covers may have several variable stages (sugar cane, for example). Each stage would have a distinctive set of spectral characteristics and would be represented by a cluster. One would indicate young plants, another matured and tasseled cane, another recently harvested, and another burned-over fields following harvesting. The task for the analyst, once initial clustering has been done, is to relate the clusters to the stage they represent and then to group all of them together as sugar cane, presuming the need is only to know the total land area devoted to sugar.

Selecting the data to go into the clustering process may be done by selecting samples (a supervised procedure) of each type of land use or cover whose location in the scene is known to the analyst. Another process, called unsupervised, is to have the computer select random samples (from either a random generator or on a fixed line column interval) with the view that such a process will naturally encounter all possible types of land uses or covers.

In the analysis of the Costa Rican test site, a combination of the above two was used. Well defined sample areas were first delineated on the CRT screen, part of the interactive operation employed in the IDIMS (Interactive Digital Image Manipulation

System) system of the Electromagnetic Systems Laboratory (ESL) in California. Numerous data points thus went toward building signatures (clusters) for each type of observed land uses. To make sure that no types were left unaccounted, randomly selected samples from the rest of the scene were also clustered.

A total of about fifty clusters were thus selected. Statistical tests were then applied to these clusters to determine how "tight" they were and far apart they were in measurement space. This was necessary to determine just how well they represented the desired uses and covers. As is usually the case in these analyses, many of the clusters were impure. That is, they contained not just data from a single feature but from several; a common case is where two spectrally contrasting uses such as a forest and a grassland are clustered together. Also, these clusters were not sufficiently separated (in measurement space) from others. As is common practice, the clusters which were impure or had a low degree of potential separability were discarded, leaving only those which were well defined and separated. Hence, a set of statistics was built from which the next step, classification, could be conducted with a reasonable expectation that classification would not be skewed through lack of an uncertain base. Out of the original fifty or so clusters, a total of 39 was retained to form the basis for classification.

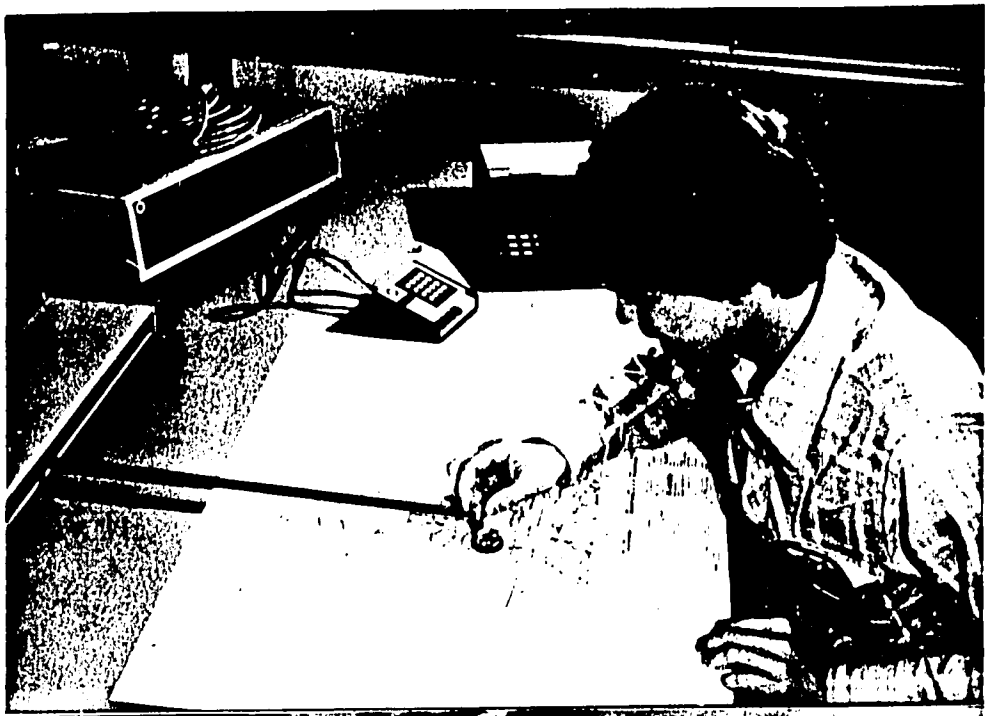
4.3.2 Classification

In the classification process, all the pixels in the scene being studied are placed into one or another of the cluster classes. Those pixels with quotient values falling in the heart of the cluster are obviously classified as being in that cluster class. The difficulty comes with those with values lying at the edge of clusters (in measurement, not surface, space) or between clusters. In these cases, the cluster to which they are assigned is determined by the "maximum likelihood" feature of the classification algorithm.

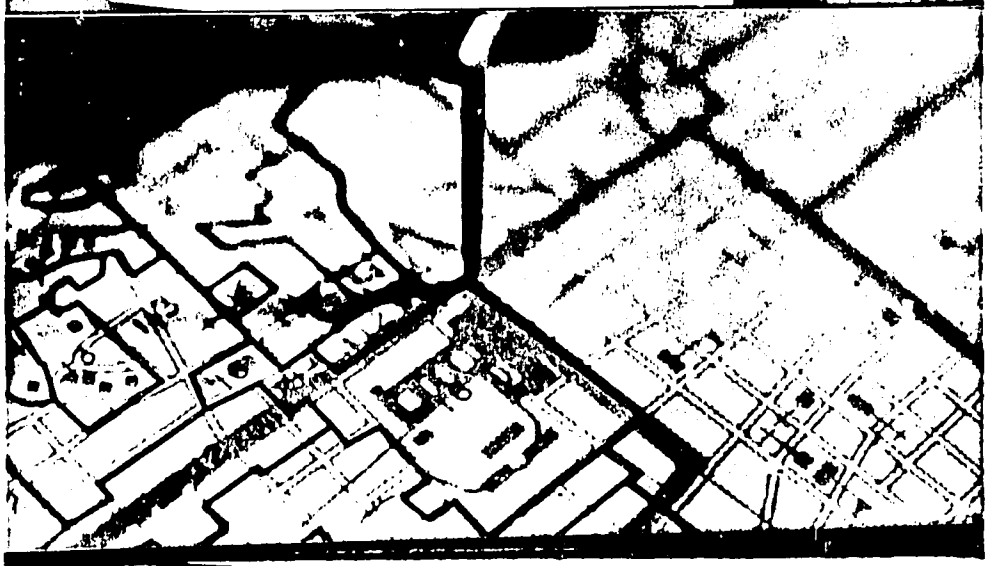
The product of classification is thus a line printer output map with alpha-numeric symbols indicating all of the cluster classes. In the case here, there was a total of 39 cluster classes.

This output was then registered to the aerial photography of the same area through use of a Bausch & Lomb Zoom Transfer Scope. This permitted establishing just what, on the ground, was being represented by the cluster classes. In this analysis a list was compiled of the final desired land uses and the cluster classes which comprised them. A total of six land-use classes were selected, each being composed of a number of cluster classes. The computer was then instructed to group the cluster classes accordingly and the result printed out in two formats. In the first, six selected alpha-numeric symbols were employed. In the second, six distinctive levels of grey were selected for use by the electrostatic grey-scale printer.

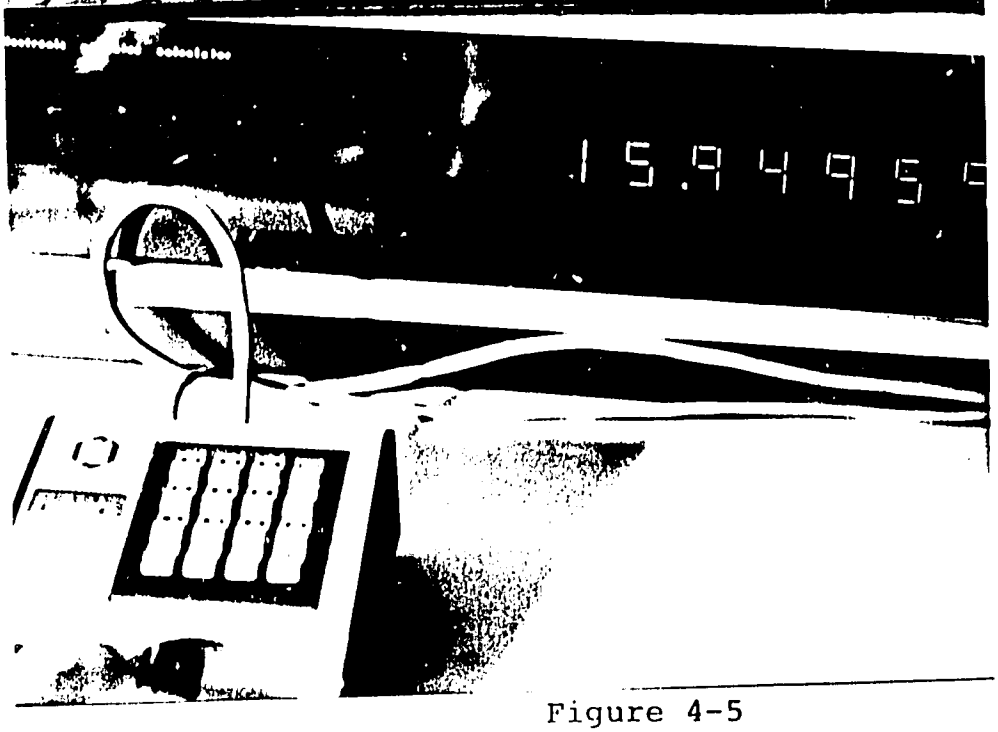
The six final land-use classes (see Figure 4-6) are further grouped into four urban classes and two non-urban classes. Much more distinction was possible. For instance, the coffee class was represented by 12 cluster classes. Since the emphasis in this phase of the demonstration project was on urban land uses, there was little incentive to explore further what the cluster classes were indicating, primarily the differences in shade tree cover over the coffee. Each of the urban classes was also composed of several cluster classes indicating some differences in reflectance characteristics of rooftops, streets, and related vegetative cover. Clearly, there is potential meaning in these differences. Inferences of differences in age and even quality -- in residential land, for instance -- could possibly be made. Such finer examination will be made in the pilot project.



The operator is working the system's cursor.



The cursor has just measured the feature polygon.



It's area (15.94959 hectares) appears on the display.

Figure 4-5
Technique used for measuring land-use polygons with the use of Numonics 1224.

Urban

Old central city

Dense concentration of small buildings, mostly residential

Light concentration of small buildings, mostly residential

Large buildings and contiguous buildings, mostly commercial-industrial

Non-Urban

Coffee

Grass plus some crop agriculture

Figure 4-6
The six classes of digitally processed data

4.4 Products

In accordance with the thrust of the demonstration project, several prototypes of maps and manipulations of data were attempted. Each product was considered to be a sample of what would result from the pilot project and eventually, upon modification if desired, the national project. Structure and method rather than full areal coverage were emphasized.

4.4.1 Base Maps for the Aerial Photo Interpretation Land-Use Inventory

An absolute prerequisite for building a baseline inventory of land use is the establishment of a systematic series of base maps, at an optimum scale, on which to place the land-use data. In the case of Costa Rica (as is true in many nations of the world) the primary topographic map series is produced at a scale of 1:50,000. While such a scale is adequate for many purposes, the inherent intensive nature of urban land use (with its attendant mandatory minimum mapping unit of no more than a hectare) requires a larger map scale. Since land use is often a function of land ownership, the ideal scale required to plot sufficient detail falls within the cadastral family of scales (larger than 1:10,000). Such maps are indeed made in particular cities throughout the world and even in the countryside in such instances as Sweden where large areas of land use are indicated or orthophoto quads of 1:10,000.

Since such large map scales are not available in Costa Rica, and generating them was beyond the scope of this project, a plan was devised to photographically enlarge the available 1:50,000 sheets to a scale of 1:25,000. The systematic approach employed was to simply divide the existing sheets into quarters and then to enlarge these with a copy camera. New "maps" were thus created, each nesting precisely within the previously existing system (see Figure 4-7).

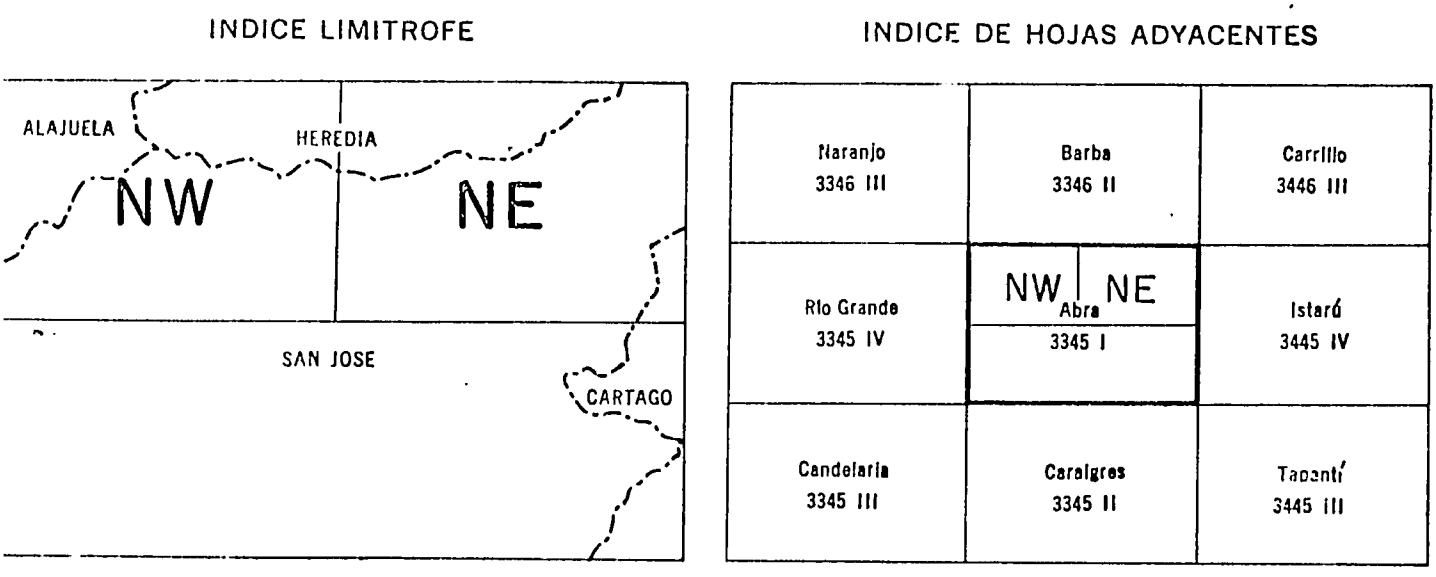


Figure 4-7
Index to the base maps. The placement of the two test maps (ABRA NW and ABRA NE) at 1:25,000 can be seen relative to the original ABRA sheet at 1:50,000.

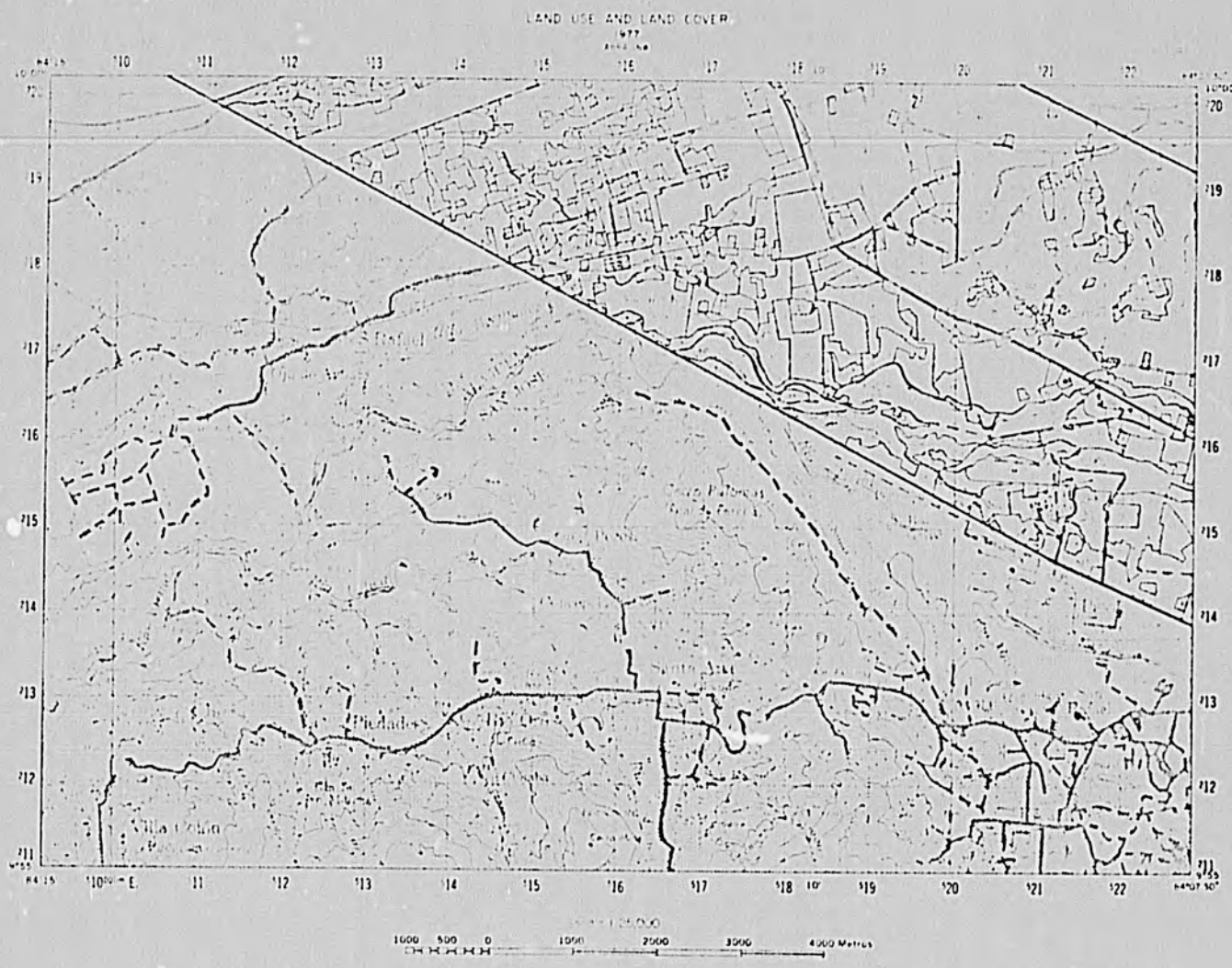


Figure 4-8
The ABRA NW map sheet. The area mapped was that covered by the flight line. Note the explanatory data and the location of the classification system (in both Spanish and English).

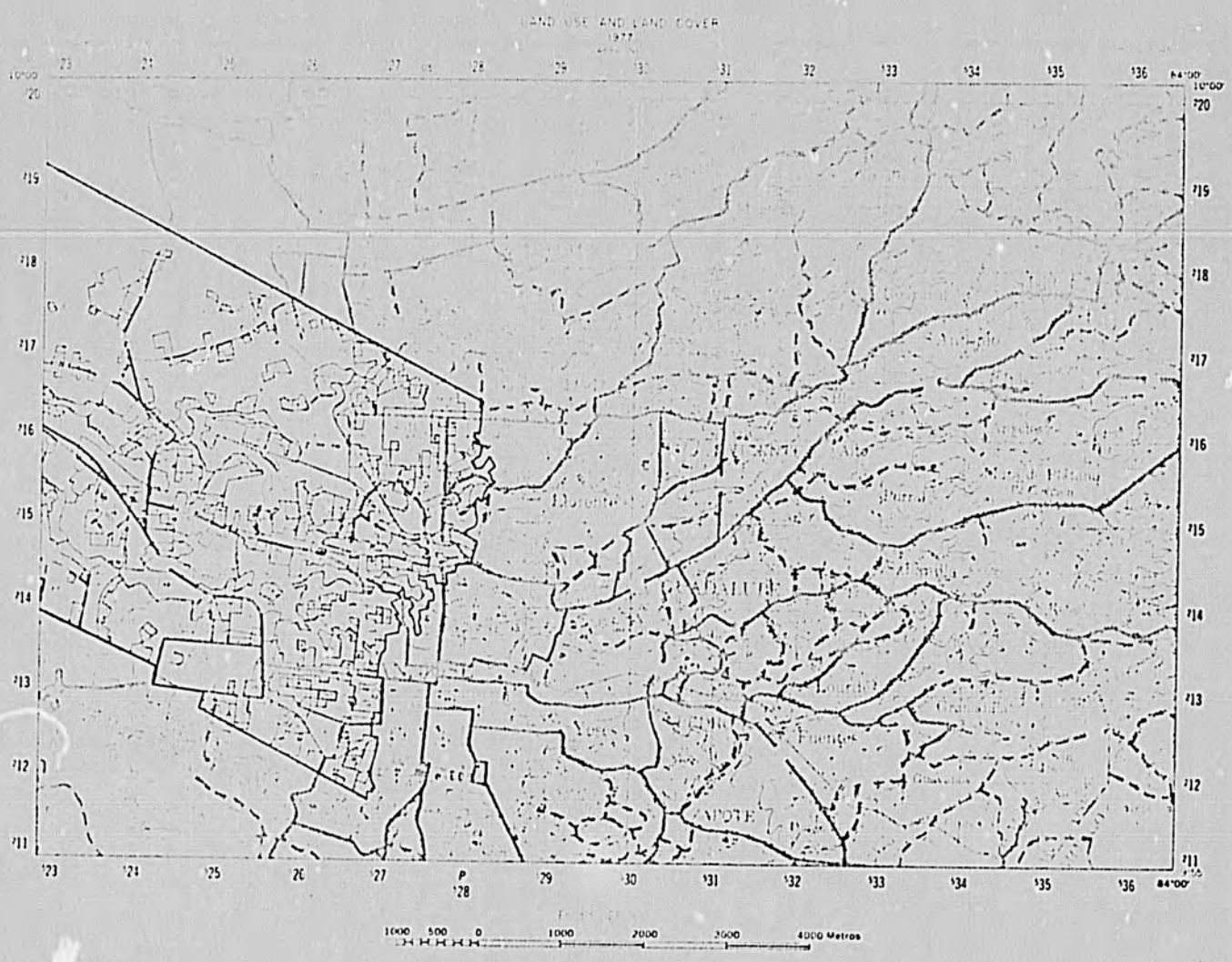
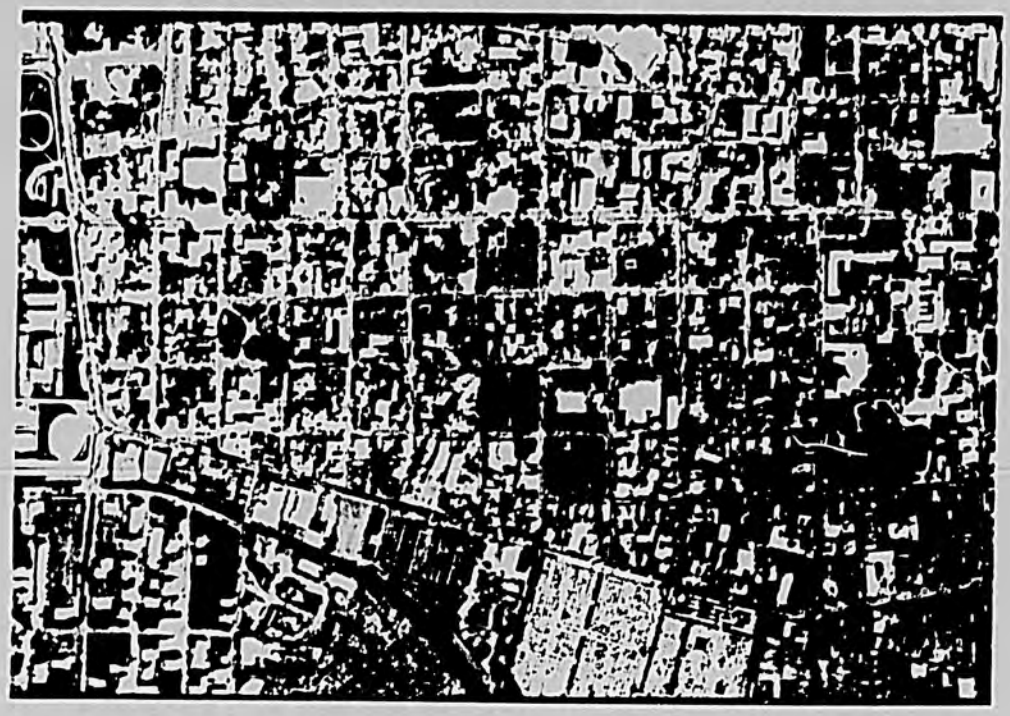


Figure 4-9
The ABRA NE topographic map sheet



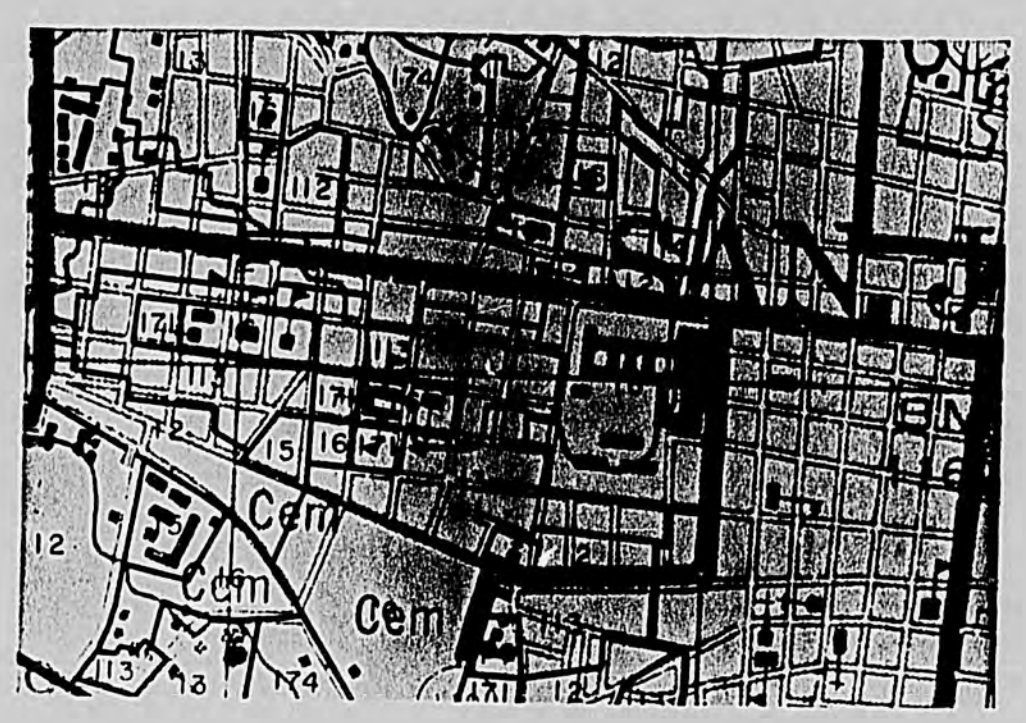


Figure 4-10
Air photograph and matching land-use map of a part of central San Jose. Note the detail of boundary placement and crisp lines possible with scribing.

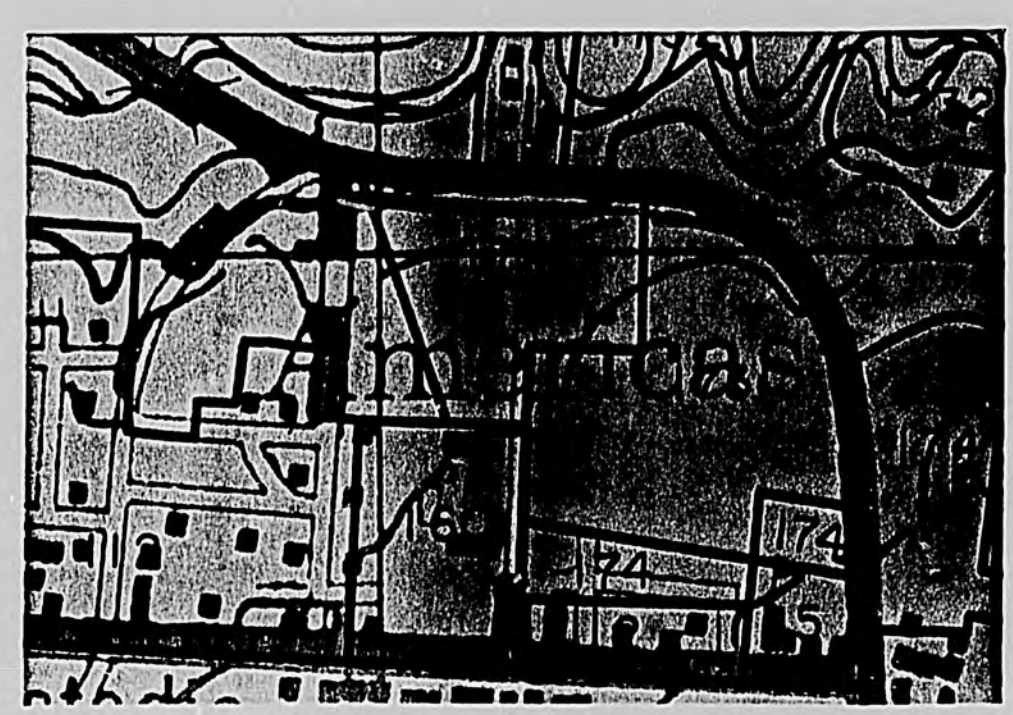


Figure 4-11
Land uses at the edge of the city. Note the evidence of change along the Autopista and the parcel of abandoned coffee land.

In the sample work done on the ABRA topographic map sheet, two new maps were created from the existing. They were labeled ABRA NW and ABRA NE. Necessary marginal information was moved to the new borders created and required index and scale information was added.

4.4.2 The Aerial Photo Interpretation Land-Use Maps

On the ABRA NE and ABRA NW sheets a large enough segment of the photo coverage was mapped to test the methods employed. The NW map (Figure 4-8) covers that part of the urbanizing corridor between San Jose and the international airport and the NE map (Figure 4-9) covers about one-half of the concentrated core of San Jose. Land-use polygons and codes are in black lying over the base map information in brown. Each map has marginal information plus a statement of method and the land-use classification system in both Spanish and English.

4.4.3 Land-Use Polygon/Aerial Photo Comparisons

Samples of the ABRA sheets at large scale are compared to matching segments of the aerial photography. With these it is possible to see, in detail, the exact placement of polygonal boundaries and to see just where some generalization was required to stay within the constraints of the minimum mapping unit. Each of the following samples also represents land use and land-use problem phenomena.

In the first set (Figure 4-10), it is possible to see the complexities of land use in a part of the core area of San Jose. Some of the uses are along streets such as the commercial-services class (number 12) bordering the Paseo Colon. In other instances, schools and related athletic fields (class 16) cover whole blocks and surrounding streets are used as borders. Most of the residential area in the scene is high density, class 113.

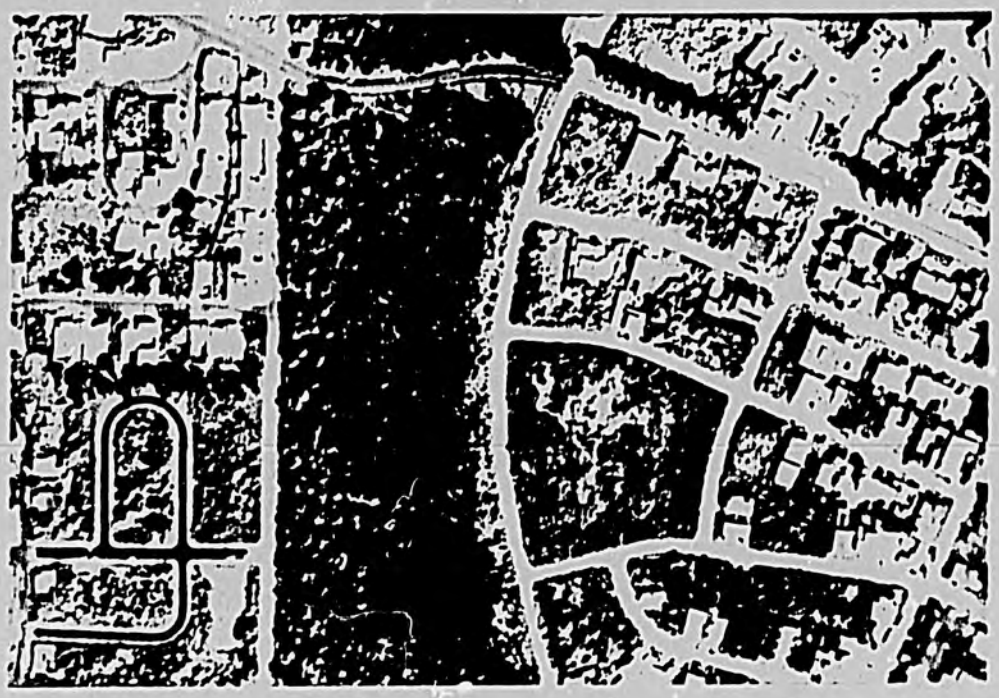


Figure 4-12
Map and photo of an area of abandoned coffee land amidst housing developments. Land in transition (class 174) lies on both sides. Note the nearly obscured access road within the coffee plantation.

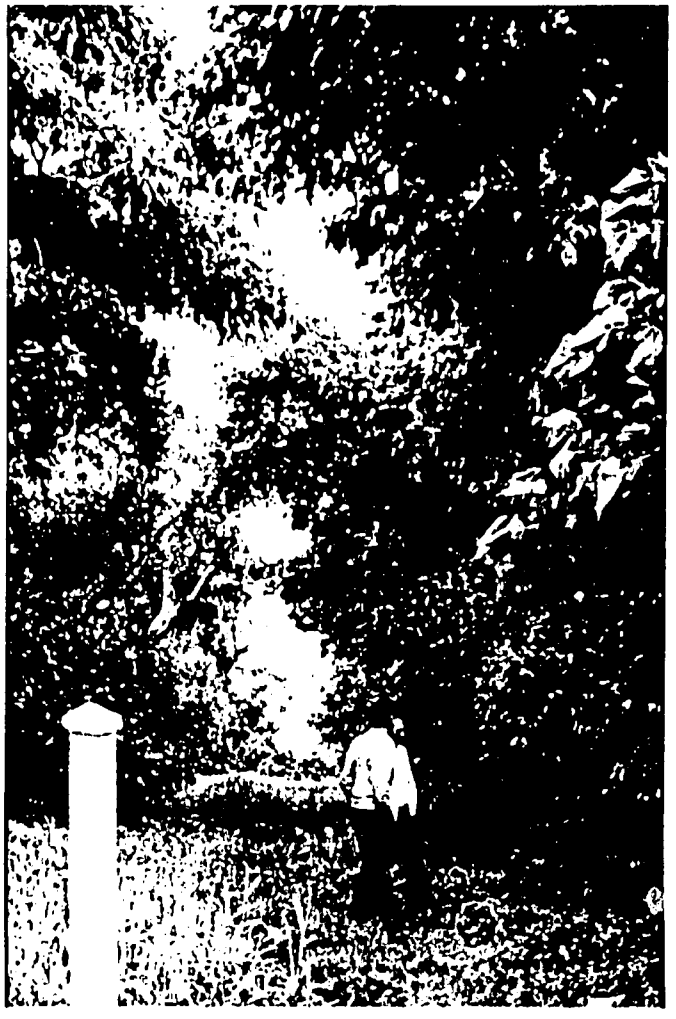
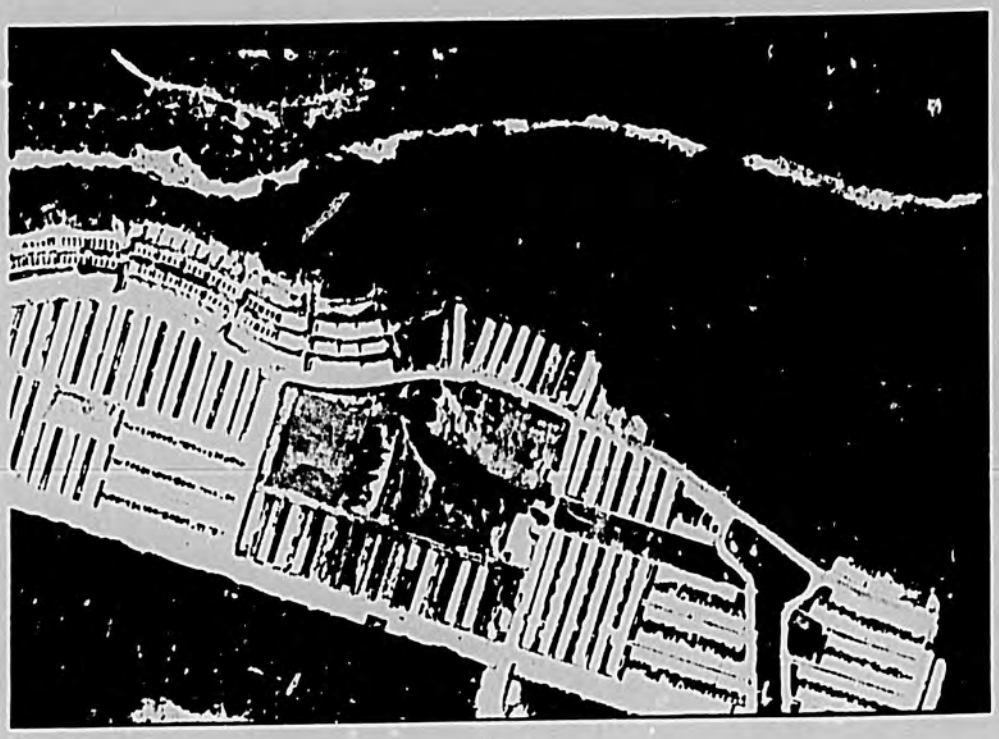


Figure 4-13
Ground views of area in Figure 4-12. INVU colleagues stand in nearly obscured access road. Land across the street is already for sale.



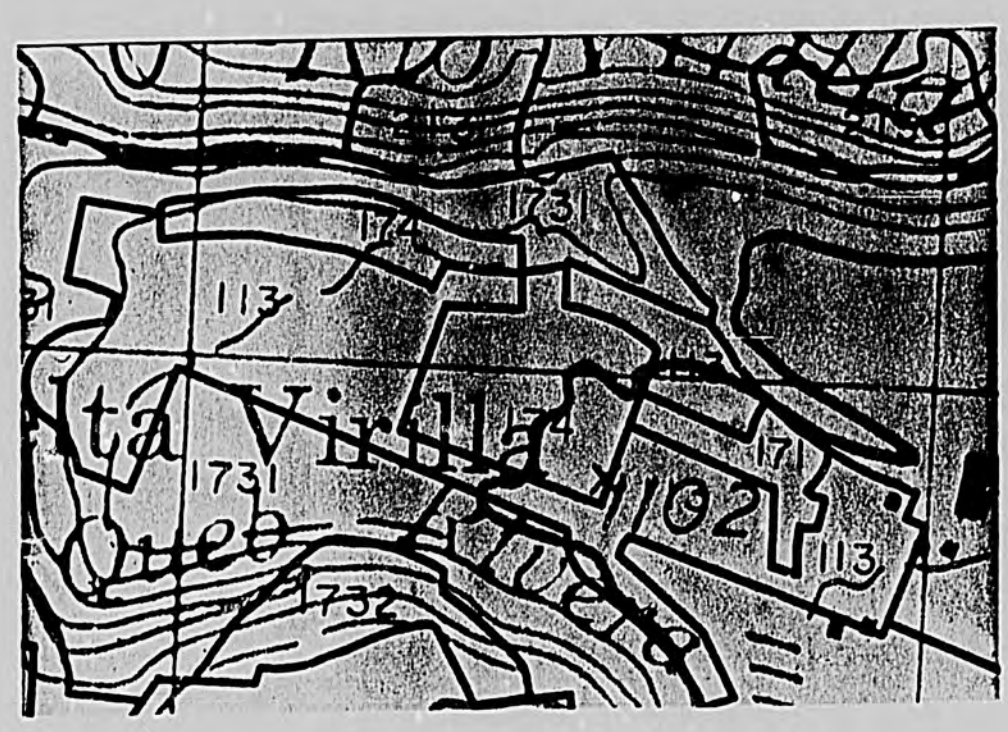


Figure 4-14
An INVU housing development near Tibas and the map recording it. Note abandoned coffee to the south and viable coffee to the northeast.

Farther toward the edge of the city (Figure 4-11) a zone of transition is seen. Here, where the Autopista to the international airport makes a big bend after passing the Sabana, there is an area of abandoned coffee land (class 1731) with a building under construction at the southeast end (the new Playboy Hotel) and a parcel at the northwest end being prepared for urban development (class 174 -- land in transition). In the western edge of the sample area, middle density housing (class 112) is seen. It is bordered on the north by other abandoned agricultural land.

Another example of abandoned coffee is seen in Figure 4-12. Near the center of the picture and at an equivalent position on the map lies a patch of this abandoned coffee between two areas of residential land, obviously in a stage of development. Clues to the state of the coffee land (mostly the unpruned shade trees) on the color infrared photograph are the rough texture and the closure of a former interior access road by the excessive growth of shade trees. This same road is seen in the bottom picture of the set in Figure 4-13. Two colleagues from INVU are inspecting the untended and non-producing coffee bushes. The other picture is taken of the edge of the coffee plantation from the parcel in transition (number 174) lying to the west. As the sign confirms, the land (itself a coffee plantation until recently) is subdivided and prepared for residential development.

Other housing developments are being constructed within coffee lands at some distance from the contiguously built-up urban area. In the instance seen in Figure 4-14, a housing development sponsored by INVU is bordered by an area of abandoned coffee on the south side (class 1731) with another patch on the north side; viable coffee (the symbol lies off the map sample) continues on the northeast side. Areas of incomplete development are placed in the transition class (number 174). Data on land in transition will be useful when growth measurement studies are made in the future.

Figure 4-15
Complex urban-rural pattern in the area near Ojo de Agua. Agriculture in such areas is being steadily converted to urban usage.

In yet another sample pair (Figure 4-15) a common land-use pattern in rural-urban fringe areas is represented. Here, near Ojo de Agua in the western part of the urbanizing corridor, residential development on small rural parcels along roadsides has created what planners in the United States often refer to as "dead land." Such parcels in the U. S., of perhaps a hectare or two, are considered to be too small to be viable economic agricultural units and too large to be landscaped ground around the house. In this example, however (at least at the present level of economic development), the land is often used for intensive vegetable production and is probably considered by the land owners to be practical. Further subdivision of property, as pressure mounts on available land, could well alter this situation in the future.

4.4.4 Land-Use Maps from Computer Processing of LANDSAT Digital Data

The high degree of detail possible in mapping urban areas through computer processing of LANDSAT data is a constant source of amazement when one considers the coarse resolution of the data in its visual form. Figure 4-16, comprising all of San Jose and the urban corridor to Alajuela, is a good example. At an enlarged scale (as shown here) of about 1:50,000, virtually all urban land uses appear in the same shade of blue-grey. At full resolution computer processing, however, fine distinctions are seen. A large building, for instance, will dominate a single pixel. At a map scale of 1:25,000 each pixel (.45 hectare) is represented by a standard pica size alph-numeric symbol (when the impact printer is set at ten symbols per inch horizontally and eight symbols per inch vertically).

Another feature of computer-aided analysis is the ease of acquiring a variety of different map outputs. Different groupings of cluster classes and other data manipulations are achieved easily and at low cost. Several types of output devices are also used to

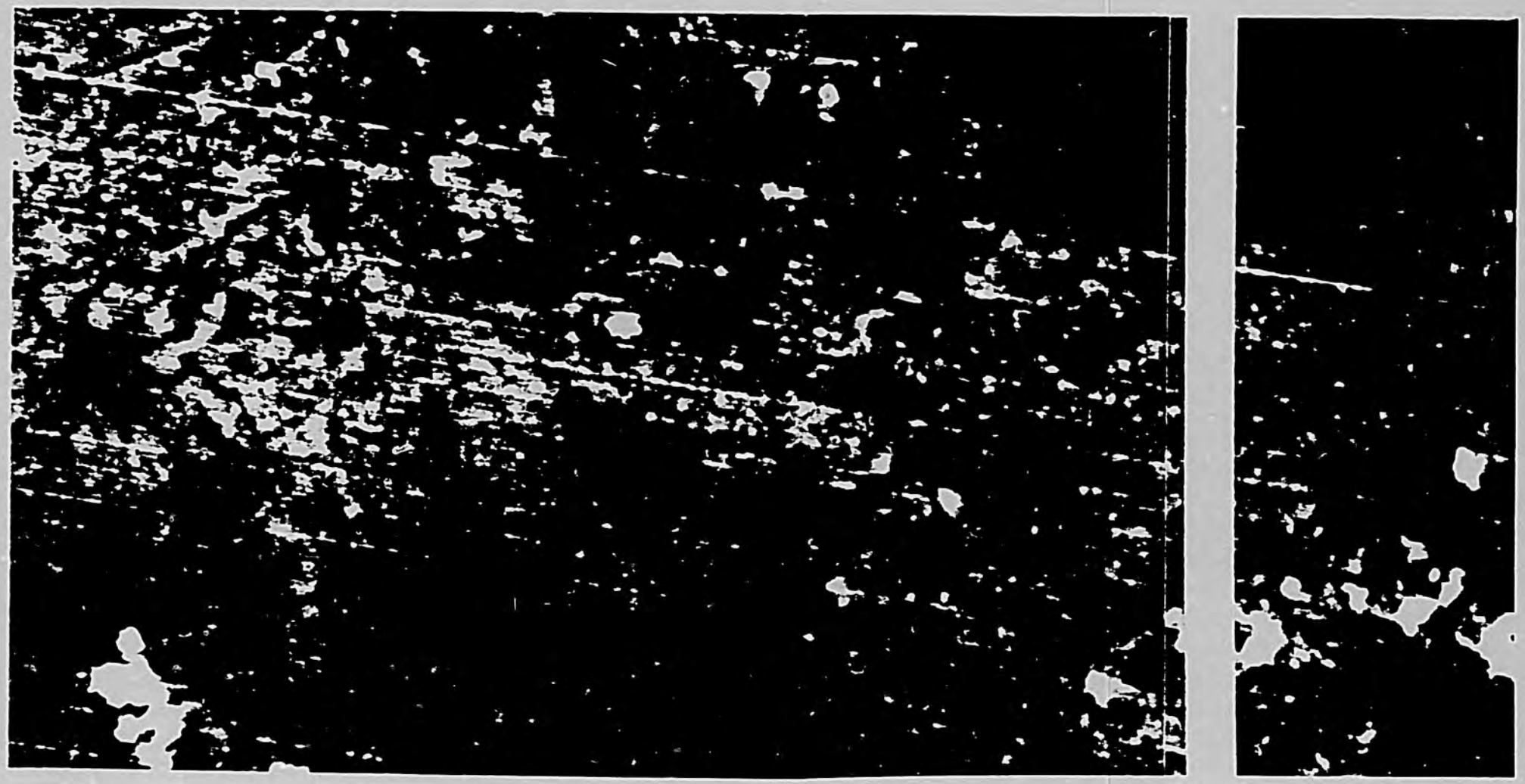


Figure 4-16
An enlarged segment of the March 1975 LANDSAT visual product from the multispectral scanner. San Jose and other urban areas appear in blue-grey. The horizontal lines are called "scan lines" created as the optical-mechanical scanners in the satellite sweep across the scene.

present classification results. For the demonstration project, the computer-processed maps were produced as:

1. Line printer output, using alpha-numeric symbols
2. Film recorder output in which each class was indicated in a different color. The computer provides instructions to the recorder to interpose combinations of filters in front of a beam of light aimed at photo-sensitive paper.
3. Electrostatic printer output displayed in levels of grey.

The simplest of these products, the alpha-numeric impact line printer output, is seen in Figure 4-17. It has been processed at full resolution so that each pixel (.45 hectares in size) has been classified and printed. This particular version is scaled to match the 1:25,000 base map sheets (note indicated relationship to ABRA NW and ABRA NE sheets) but is not rotated to align symbols in a east-west, north-south direction. Such rotation is a relatively trivial step and would normally be employed in any production-oriented effort. This product has been colored by hand, with point-line features added for reference purposes.

A sharp distinction is visible between the urban classes (in red, yellow, orange, and violet) and the non-urban classes (brown for coffee and green for other agriculture, most of which is pasture). Urban land uses which lie north of the Rio Tiribi and west of the Sabana have largely replaced coffee plantations. Coffee lying just to the south of the river and remnants within this urbanizing sector are all that remains of a once larger area. Evidence of urban incursion is also seen in the broad belt of land devoted to coffee lying to the north of the Autopista. Within the urban classes, the pixels colored red represent the high density type of development associated with the old central section of San Jose and the satellite towns. Narrow streets, weathered rooftops, and densely set buildings have a distinctive collective signature. Middle density residential land is represented by orange; lower densities are in yellow. The

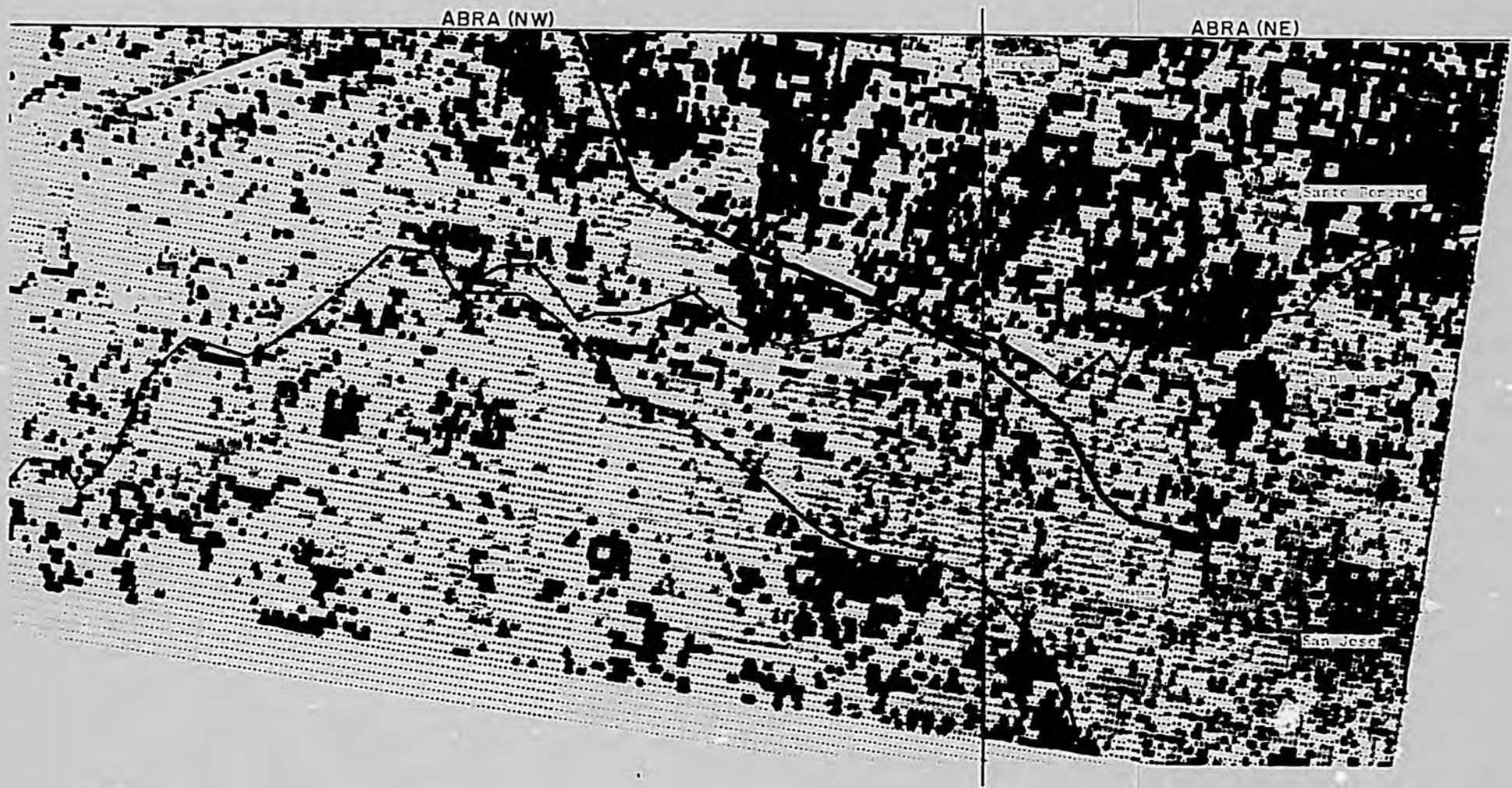


Figure 4-17

A line-printer output map of land use derived from computer processed LANDSAT digital data. Note base map designations of ABRA NW and ABRA NE. Scale of the original is 1:25,000. Red is old central city; orange is dense concentration of small buildings, mostly residential; yellow is light concentration of small buildings, mostly residential; violet is large buildings and contiguous buildings, mostly commercial-industrial; brown is coffee; and green is other agriculture, mostly pasture and grass.

violet is intended to indicate large, bright industrial-commercial structures. Some new, highly reflective residential areas in Pavas are misclassified as industrial-commercial. Further refinement work will be required to make separations clear. Urban signatures are also recorded at Coco International Airport because of the large area of concrete forming the runways and ramps. No particular problem is envisioned with this type of "misclassification" since a feature such as an airport can easily be demarcated from existing maps and the pattern of an airport is distinctive in itself.

The film recorder output (Figure 4-18) of the whole area for which computer processing was undertaken (rather than just the area of the ABRA sheets) serves to demonstrate a type of product which has high potential value as a final display. Its utility, however, would not seem to justify its cost to provide a working, interim map. Final project maps of this type are usually further enhanced by the addition of point-line features, a grid, and requisite scale and locational information. Such a product, for the entire built-up area of the Meseta Central, might be ideal of the pilot project.

The electrostatic grey-scale printer output, on the other hand, is low cost and provides the kind of base information which can be readily used in numerous ways in the process of spatial analysis. All possible increments of enlargement, for instance, are simple options to the machine operator. The only limitation is the width of the roll of paper; as an absurd example, a single pixel could be 56 centimeters on a side.

In the example seen in Figure 4-19, the scale of the original full resolution classification was produced at three times enlargement giving a pixel size (in the original) of nearly one centimeter. The inherent sharp distinction provided by assigning the two lightest shades to the non-urban classes and the darkest to the urban was an aid in separating rural from urban uses.

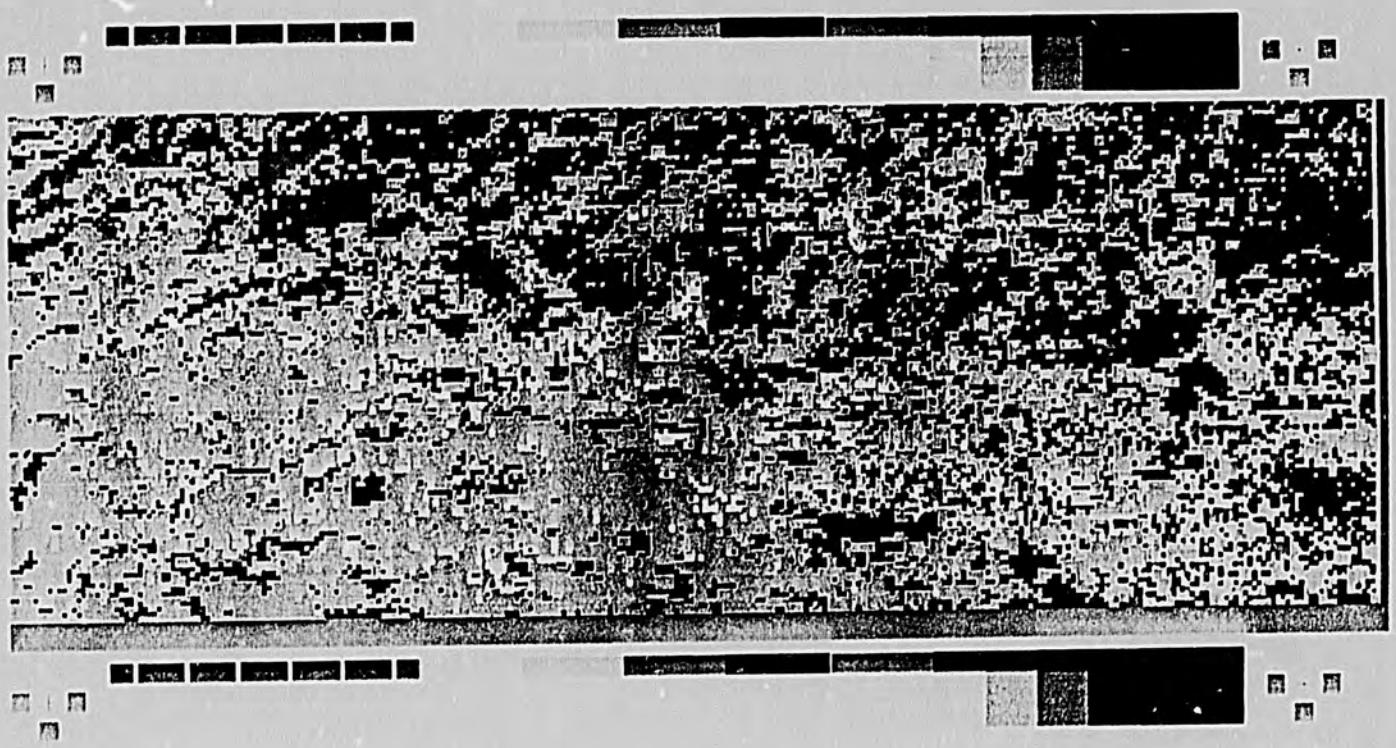


Figure 4-18
Film recorder output of computer processed LANDSAT digital data. San Jose lies in the southeast corner and Alajuela is in the northwest corner.

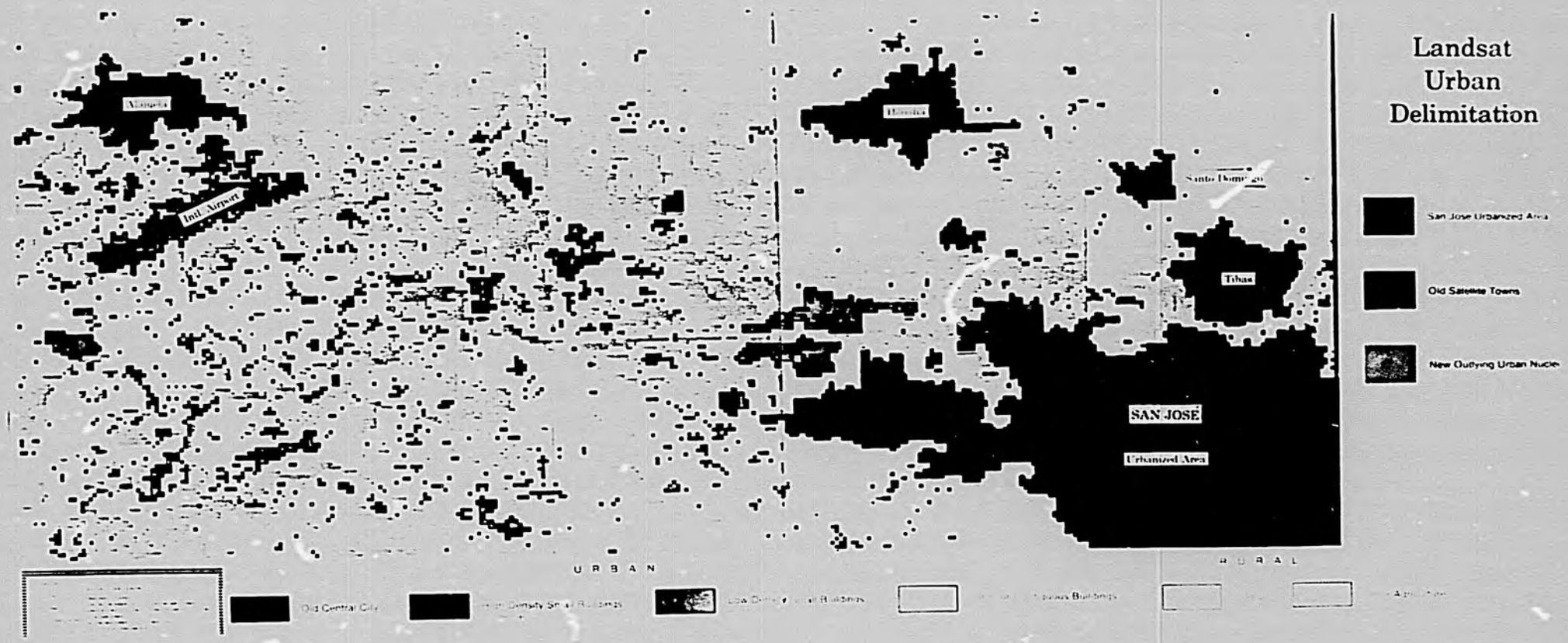


Figure 4-19

LANDSAT urban delimitation. The urbanized area was delimited by connecting individual, contiguous picture elements (pixels) which represent urban land use as detected by computer processing of LANDSAT digital data. The boundary line was extended to a length of two pixels (160 meters) to include discontiguous urbanized cells. Embayments were bridged when the opening did not exceed the length of two pixels.

Further manipulation of the map resulted in a delimitation of the urbanized area of San Jose, the bounding of the contiguously built-up portions of the satellite towns near the city, and the identification of urbanizing nuclei lying beyond the built-up area. A systematic scheme was developed to direct the drawing of the outer perimeters of each of these types, represented by the red, the blue, and the yellow on the map. A method used by the U. S. Census Bureau in its delimitation of Urbanized Areas was adapted for use with remotely sensed data. While the Census Bureau employs statistical reporting units as building blocks (enumeration districts and corporate units mostly) and makes only slight reference to urban land uses, the method shown here for Costa Rica uses only urban land use as derived from processing satellite data. The scale of the work in this example is also much more detailed than that of the Census. For example, the Census will consider a detached urban enclave to be a part of an urbanized area if it lies less than one and one-half miles away; the intervening area is "bridged" on a map. In the method employed here, an urban land-use enclave was included within the contiguous urbanized area if it were only two pixels (160 meters away). Similarly, urban enclaves (those rural areas penetrating into the mass of the city were included in the urban mass if their openings on the outer perimeter were no wider than 160 meters.

Several advantages accrue from using this method. First, the boundary is very finely detailed, much more so than the method employed in the United States based on ground-collected data. Second, since the method depends on satellite data, information for subsequent delimitations can be obtained with great frequency; the U. S. Census urban delimitation can be done only every ten years. Third, the way is clearly shown by which urban growth can be monitored on a regular, periodic, systematic basis, especially in a developing nation unencumbered with a traditional system.

In an overall view of the two part map in the figure, one can easily see that all of the satellite towns are perilously close, according to the delimitation system, of being engulfed by the expanding San Jose urbanized area. The urbanizing nuclei could also easily coalesce into larger units. Note that only those nuclei of ten or more hectares were assigned a yellow pattern; those of smaller size are numerous but equally demonstrate the urbanizing process.

Yet a further manipulation of the same data was made in identifying urban and urban-related regions (Figure 4-20). Proceeding from the previous urbanized area delimination map, dominant land-use patterns were employed to delimit regions. Of great portent is the San Jose - Alajuela urbanizing corridor covering a zone which stretches on both sides of the Autopista. Other important regions are the small farm and string settlement region south of the international airport and the region of future residential subdivision development to the south of the Rio Virilla. While similar maps may be drawn based on local knowledge, the support given by satellite data not only lend credibility but provides a base for measurement and the establishment of systematic delimitation criteria.

4.4.5 Comparison of Photo Interpretation and Computer Processing

Since the inception of computer processing of LANDSAT data for the making of land-use maps, attempts have been made to achieve levels of detail which equaled those associated with mapping land use from aerial photographs. The principal difficulty always encountered results from a fundamental difference in the data bases. Aerial photographs contain not only information on color, size, shape, texture, and tone of a feature but contextual, spatial relationship data as well. The interpreter calls upon all of these in the process of classification. The analyst of LANDSAT digital data, by contrast, has only spectral reflectance data and, when typical machine

SAN JOSE TO ALAJUELA URBANIZING CORRIDOR, SATELLITES AND ASSOCIATED REGIONS

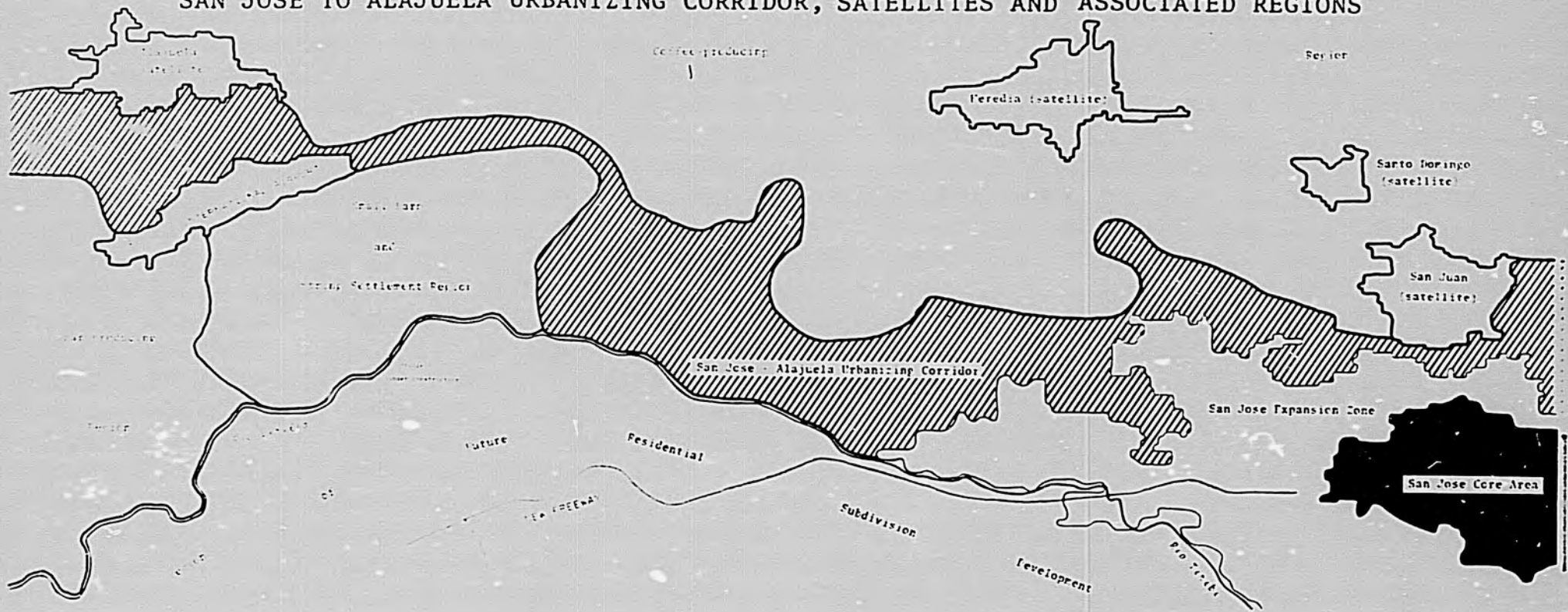


Figure 4-20
A map of dynamic growth regions. The data were derived from computer processing of LANDSAT digital data displayed on an electrostatic grey scale printer.

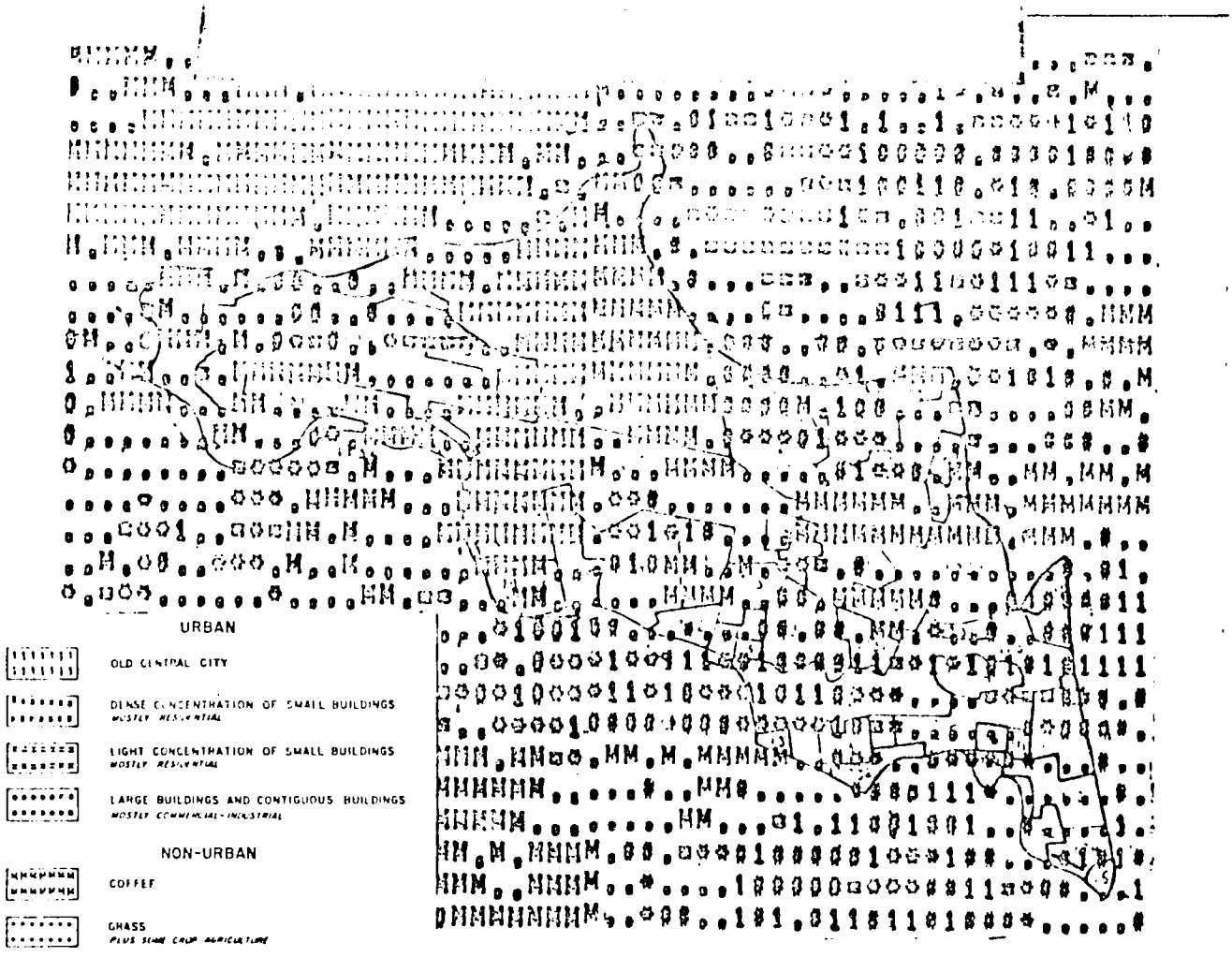
processing is employed, none of this is in a contextual spatial relationship.

Accordingly, the photo interpreter is able to achieve a classification which emphasizes the functional character of each land use: in this he is merely extending the surface observation view of the ground observer to the vertical, synoptic view one gets from the air. The digital analyst, on the other hand, must infer function from the physical, morphological data which the satellite provides. As a result, the classification done from satellite data usually contains a strong physical component, such as bright rooftops versus dark rooftops. Inference of function can be achieved only through reference to some other form of visual data, as indeed was done in this project.

As far as it was possible in the demonstration, a comparison was made of the results of the two classification systems. The only complete administrative district in the test area, Distrito Cinco Esquinas, was chosen for this phase of the demonstration. The outer boundary of the district is seen in black outline on the natural color photo (Figure 4-21). Contained within is a variety of uses, both rural and urban. A new INVU housing tract denotes the western section; both viable and abandoned coffee lands are present; some new industrial-commercial development is present; and some residential land occurs.

In order to see the relationship between the two mapping systems in the same area, the photo interpretation map is superimposed over the digital map (Figure 4-22). An attempt to find perfect correlation is placed at an immediate disadvantage because of incompatible data bases. The photography is from late 1977 but the satellite data goes back to March 1975. As may be inferred from the photography (and confirmed by examining earlier photographs not displayed here), considerable change has occurred in the last two years. The INVU housing tract expanded and some of the land in transition in the southern part of the district was still in coffee at that time.

Figure 4-21
A natural color aerial photograph of a part of San Jose and its environs. (Tibas lies in the northwest corner.) The outlined area is the boundary of the administrative reporting unit Distrito Cinco Esquinas.



Land-Use Classification System for Air Photo Interpretation Mapping

Class Number	Class
	URBAN
111	Residential (low building density)
112	Residential (medium building density)
113	Residential (high building density)
12	Commercial and services
13	Industrial
14	Transportation, communications, and utilities
15	Industrial and commercial complexes
16	Institutional
171	Recreation
1721	Coffee (viable)
1722	Other agricultural land (viable)
1731	Coffee (abandoned)
1732	Other agricultural land (abandoned)
174	Vacant land in transition

Class Number	Class
	NON-URBAN
211	Sugar Cane
212	Field Crops
213	Other (including small, fenced pastures)
221	Coffee
222	Bananas
223	Palms
224	Greenhouses
23	Agricultural Structures
3	Rangeland (grass)
4	Forest Land
51	Streams, canals
52	Lakes
53	Reservoirs
72	Beaches
74	Bare, exposed rock
75	Strip mines, quarries,

Figure 4-22
A sample of digital mapping line-printer output with an aerial photo interpretation overlay (Distrito Cinco Esquinas).

Despite this problem and that of the inherent differences in the two systems, there is still a high degree of agreement between the two maps. This agreement was quantified and the results placed into a comparison matrix (Figure 4-23). In the matrix, it may be seen that the classes, through bearing different titles, may be related to each other; the photo interpretation classes "nest" within the LANDSAT. Sometimes the comparison is direct, as is the case of high density residential (the photo interpretation class) and dense concentration of small buildings (the LANDSAT class). In others, the LANDSAT class (large buildings, contiguous buildings, for instance) comprises classes number 13, 14, and 15 of the photo interpretation group. Similarly, there is only one coffee class by computer processing and three by photo interpretation. It is particularly interesting to note that the totals are reasonably close by major class units. The urban area, as composed of classes derived from photo interpretation is 96.3 hectares while the urban classes tabulated by LANDSAT are 85.0 hectares. The majority of this difference is directly traceable to new urban construction occurring after the LANDSAT data was obtained. A similar relationship is seen in the comparison of 194.4 hectares for the photo interpretation to 219.6 hectares for the satellite. Further such comparisons for more districts and with more compatible data would be an interesting exercise in the pilot project.

4.5 The Effectiveness of Remote Sensing for Urban Area Assessment

Urban areas everywhere in the world share a set of conditions which bear upon the problem of mapping, storing, manipulating and using land use data. Three problem areas are frequently encountered.

1. Parcels in a particular use are much smaller than ordinarily found in rural areas. A large map scale is thus required to show essential detail.

LANDSAT AND PHOTO-INTERPRETATION COMPARISON MATRIX

	PHOTO INTERPRETATION \ LANDSAT	URBAN: Old Central City	URBAN: Dense Concentration Small Buildings	URBAN: Light Concentration Small Buildings	URBAN: Large Buildings Contiguous Buildings	NON-URBAN: Coffee	NON-URBAN: Mostly Grass	TOTAL HECTARES	
URBAN	(12) Commercial, Services	X						4.3	96.3
URBAN	(16) Institutions	X						1.5	
URBAN	(113) High Density Residential		X					28.6	
URBAN	(112) Med. Density Residential			X				14.0	
URBAN	(15) Commercial, Industrial				X			8.4	
URBAN	(13) Industrial				X			30.4	
URBAN	(14) Utilities, Transport				X			9.1	
NON-URBAN	(221) Coffee					X		52.9	194.4
NON-URBAN	(1721) Viable Coffee					X		11.0	
NON-URBAN	(1731) Abandoned Coffee					X	X	64.8	
NON-URBAN	(1732) Abandoned Other						X	13.0	
NON-URBAN	(174) Vacant						X	48.3	
NON-URBAN	(171) Recreation						X	4.4	
	TOTAL HECTARES	12.9	42.3	18.4	11.4	111.0	108.6	304.6	
		85.0				219.6			

Figure 4-23
LANDSAT and photo interpretation comparison matrix

2. Dynamic economic forces present in the city tend to cause rapid change in the land use of a parcel. Significant is an economic pre-emption order which gives preference to the most intensive use; residential land is often pre-empted by commercial usage.

2. Only in the city is there a multiplication of surface space in the form of multi-story buildings where, frequently, higher order uses command ground floor space and lower value uses occupy the upper floors.

These characteristics bear on urban land-use studies by:

1. Either requiring inordinately expensive and perishable studies

or

2. Discouraging urban planners from undertaking them, or if they do, from maintaining their currency.

Even in developed countries, and in planning agencies in particular, the obstacles to maintaining such maps are so formidable that few cities do so. The arrival of recently developed remote sensing techniques, however, has spurred several attempts to remedy this situation. Statute laws (in the United States) have further required that land-use inventories be developed and maintained. The possibilities of using satellite data with its relatively low cost for repetitive coverage, has become quite attractive.

The first problem is to determine a realistic and appropriate urban land-use mapping system. Once this has been done attention must be paid to another group of constraints which are peculiar to the city they are:

1. Scale: A large base map scale is required to indicate with precision the variety of uses found in a typical urban core area. This especially so if diverse uses are found at different levels in multi-story buildings. A smaller scale, however, may suffice over large areas of homogeneous land use, such as residential, nearer to the periphery of the city.

2. Accuracy of Classification: Accurate classification is often difficult through use of aerial photography where only the rooftop may be seen; oblique photographs are useful as a support. Observation from the ground is the most accurate, although not necessarily the most cost-effective.

3. Accuracy of Placement of a Land-Use Polygon on a Map: From ground observation, where only the street front of a land use is visible, it is difficult to know the areal extent of a land use. Here, remote sensing has an advantage.

4. Area Measurement: Accurate measurement of a land use is a function of how accurately it is placed on a map, if not measured directly from the original photography or satellite data.

5. Land-Use/Parcel Ownership Conflicts: Lack of agreement exists on the relationship between ownership and its use. Data on land, by parcel ownership, is often available as part of a tax assessor's record. When there is more than one land use per parcel, the data do not describe the real nature of use.

Acting as a balance to these problems are several characteristics of land use in the city which may be used to advantage by the planner. The most general is that order does exist in the urban landscape. Land use does follow reliable, replicative patterns simply because man reacts universally to universal socio-economic and political stimuli. Highest value lands, and usually the tallest buildings, are located at the point of greatest accessibility; industries locate along transportation arterials, and so on. A positive correlation is also observable between building morphology and the function it serves. In short, the city has a number of distinctive signatures and these replicate from one city to another, certainly within a single culture. Thus, the analyst who employs remote sensing as a tool can count on certain recurring patterns. Accordingly, "ground truth" samples serve well to make land-use identifications in similar urban situations.

In the city, as elsewhere, there exists the full range of data sources for conducting land-use studies. At the simplest level there is the direct visual observation of land use and its recording on a map. This may be done on foot or by vehicle ("windshield

surveys"). Then, in remote sensing there are several scales of aerial photography and both visual and computer processed digital data from satellite. Each approach has certain advantages and disadvantages. When the needs of a particular city are examined, the suggestion may be made that a combination, a multi-sensor, approach might be the most desirable. In the San Jose, Costa Rica instance, detail in the old central city can only be obtained by direct observation and a mapping on a building-by-building basis. For other areas of the city, large and even small scale photography of sufficient resolution quality would seem to serve well. For general views, visual satellite data has a place and for a growth monitoring system, at a sufficient level of detail, the computer processing of satellite data would best be used.

A discussion of land-use classification relative to the levels prescribed by Anderson, et. al. (1976) inevitably leads to the controversy, mentioned earlier, between the physical morphological characteristics of the urban landscale and function land use. Disregarding Level I where all "urban" is but a single class, the limits of aerial photography and digital data may be probed. As demonstrated in the examples in this section, Levels I, II, III and IV are all identifiable from the aerial photography used in the project. The most significant point to make is that detail is available where it is needed, namely in the dynamically changing rural-urban fringe area. The fine detail required in the central city, where the largest possible map scales and direct visual observations must be used, is not at issue here.

Nor must the potential detail in satellite digital data be ruled out. While the system does not provide the same level of detail in functional land-use classification, detailed information on the spectral characteristics of various urban land covers within the city has enormous potential use. Some of the data (of the spectral classes) which has been discarded may very well have value in such physically related problems as urban hydrology and micro-climatology. Some of this information, if it were to be placed

in context of the levels of functional land use, would fall within Levels III or IV. For the most part these are moot points; the Anderson classification system was designed to treat visual, not spectral, data.

The best estimate of effectiveness of the use of remotely-sensed data as applied in the urban demonstration project is:

1. The aerial photography, especially the larger scale, is ideally matched to the classification scheme and base map scale adopted. Photography of a larger scale would represent an unnecessary cost: smaller scale photography with the same camera/film/filter system would not provide sufficient detail. Camera systems with higher resolutions could be employed, although usually at greater cost.
2. Natural color photography is generally the most useful since the interpreter does not have to "translate" signatures. The slightly greater amount of atmospheric haze is of little consequence at the low altitude at which the larger scale photographs are taken.
3. Color infrared has its greatest utility in urban land-use mapping at the edge of the city, where distinction is attempted in searching for degrees of difference in active and abandoned agricultural land.
4. Computer-processed digital data from LANDSAT has the immediate utility of making a sufficiently sharp distinction between urban and rural land uses to be able to demarcate the edge of the city, and therefore permits change detection and monitoring of growth. It most cases, the resolution is adequate for the purposes intended.

5.0 A COST-EFFECTIVENESS COMPARISON

Before any effective resources management or regional development plan can be formulated, it is obviously necessary to have at least some idea of what is to be managed or developed, its location, extent, and current condition. Unfortunately, in most tropical areas of the world, this 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 resources survey and data gathering activities, a scarcity of trained professional personnel, and the constraints of weather. Remote sensing from aircraft or spacecraft, with its promise of rapid and inexpensive data collection over large areas, offers a possible solution to this information problem.

The objective of any natural resource inventory or survey operation is to provide a decision-making agency with more complete, more accurate, and/or more reliable information concerning the resource base and its condition than was originally available. This information is then of economic value to the extent that it enables the user to reach a "better" and more informed decision than he could in its absense. If the resource is a dynamic or endangered one, changing rapidly with time, the user may need repetitive data at frequent intervals. If small changes may have major economic significance in certain areas, high resolution data may be required. In any event, the nature of the resource problem and the level of management intensity desired will define the type, quantity, and frequency of information that must be generated.

One objective of the Costa Rican "demonostration" project was to determine the relative cost-effectiveness of alternative approaches to:

1. Monitor the forest resources of Costa Rica
2. Monitor the impact of urban sprawl on agricultural resources.

These are obviously separate requirements, with separate constraints on resolution, repetitive coverage, and similar factors. The investigation was made somewhat more difficult in that final "desired" map scales could not be specified in advance by the user agencies. An additional objective of the demonstration project was then to determine what might be practically produced in Costa Rica and, through conferences with the respective agencies, determine which product type might be most useful in terms of current GOCR objectives and ability to utilize and act upon the information presented.

5.1 Forest Resource Assessment

The principal technical conclusions regarding the effectiveness of remote sensing technology for forest sector assessment in Costa Rica were:

1. A Level I forest and vegetation cover map series at a scale of 1:200,000 is required by the Forestry Department for regional resource assessment purposes.
2. Such a map may be compiled at an acceptable level of accuracy from medium scale aerial photography or from digitally analyzed LANDSAT satellite data. Visual interpretation of satellite imagery cannot, by itself, produce a forest cover map of sufficient accuracy.
3. An annual or bi-annual update of such maps is highly desirable.
4. If intensive forest management is an objective of the GOCR, then the existing 1:50,000 scale topographic maps will form an excellent information base. Forest stand information at Levels II, III and IV may be compiled at this scale.
5. Forest stand information at Levels II and III is readily obtained from aerial photography at acquisition scales of 1:20,000 to 1:50,000. Level IV data may typically be obtained from 1:20,000 or larger scale photography when supplemented by intensive ground survey.

6. Natural color photography is preferred at lower altitudes (larger scales). Color infrared is preferred at higher altitudes. In terms of information content, both are superior to panchromatic photography of equal scale. Multispectral photography is not recommended for operational use at this time.
7. Digitally analyzed LANDSAT satellite data is marginally acceptable for forest stand information at Level II in Costa Rica and in general unacceptable at Levels III and IV.

The principal forest sector data requirements in Costa Rica, neglecting for the moment any requirements for frequency of updating, are then Level I forest cover maps at a scale of 1:200,000 and approximately Level III maps at a scale of 1:50,000.

5.1.1 Level I Forest Resource Maps, 1:200,000 Scale

Level I maps at this scale may be produced directly from LANDSAT satellite data in digital form or through manual interpretation of panchromatic or color infrared (CIR) photography acquired at a scale of 1:40,000 or from natural color photography acquired at a scale of 1:20,000. The 1:40,000 acquisition scale requires a flying height of 20,000 feet above terrain when a typical mapping camera is used with a six-inch lens. This is well within the range of equipment currently available in Costa Rica. Natural color photography is normally attempted at high altitudes only when atmospheric haze is not expected to present a problem. Conditions in most tropical areas of the world limit its use to altitudes of about 10,000 feet, or a scale of 1:20,000.

Data collection, processing, analysis and draft map compilation costs for each of these alternative approaches are summarized in Table 5-1. Parameters used to arrive at these costs are presented in Table 5-2. At this level of detail, there is no major difference in final product accuracy between these alternatives. If anything,

	LANDSAT (Digital)	Pan (1:40,000)	CIR (1:40,000)	Color (1:20,000)
Data Collection Costs[1/] (34,000 Km^2 area)	$200	$3,400	$8,000	$15,600
Data Processing	6,300	900	2,000	4,600
Interpretation/Analysis[2/]	1,500	2,600	2,600	5,300
Compilation[2]	[3/]	1,600	1,600	6,500
Totals	$8,000	$9,300	$14,200	$32,000
Data Collection Time[4/]	Nil	8 Days	9 Days	18 Days
Draft Map Production Time[5/]	0.5 Months	6 Months	6 Months	19 Months

1/ Does not include ground data collection and field checking costs, common to each alternative

2/ Costs to generate and compile working draft map at 1:200,000 scale. Does not include final drafting, scribing or other costs of inal production common to each alternative.

3/ Compilation included as part of data processing. Product output is line printer map at 1:200,000 scale.

4/ Assumes weather is not a factor in data collection.

5/ Includes interpretation/analysis and compilation time only. Data collection, processing, and shipping time would be additional.

Table 5-1: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL I FOREST RESOURCE DATA IN COSTA RICA AT 1:200,000 SCALE

LANDSAT			
Data Collection: CCT		$ 200	
Data Processing:	@ 48¢/mi^2; 13,127 mi^2	6,300	
Interpretation/Analysis/Compilation		1,500	
			$8,000
Pan, 1:40,000			
Data Collection:	1,650 hours ÷ 225 frames/250 feet roll 8 rolls @ $122.03 + $5 shipping/roll	$1,016	
	1 ea. 4-hour mission/film roll for cloud-free photography 8 missions = 32 hours @ $100/hr for GOCR aircraft and crew	3,200	
Data Processing:	@ 40¢/ft, 250 ft x 8, plus $10 shipping/roll	900	
Interpretation/ Analysis @ 1:40,000:	1,650 frames @ 3 frames/hr 550 hours @ $4.80 (composite GOCR rate)	2,600	
Compilation @ 1:50,000, Transferred to 1:200,000:	1,650 frames @ 3 frames/hr 550 hours @ $2.90 (GOCR rate)	1,600	
			$9,300

Table 5-2: COST PARAMETERS, LEVEL I - FOREST; 34,000 Km^2 AT 1:200,000

CIR, 1:40,000			
Data Collection:	1,650 frames ÷ 200 frames/200 ft roll 9 rolls @ $4 0.51 + $5 shipping/roll	$4,370	
	1 ea. 4 hr. mission/film roll 9 missions = 36 hours @ $100	3,600	
Data Processing:	@ 94¢/ft, 200 ft. x 9 plux calibration and shipping @ $30/roll	2,000	
Interpretation/ Analysis @ 1:40,000:	1,650 frames @ 3 frames/hr 550 hours @ $4.80/hr	2,600	
Compilation @ 1:50,000, Transferred to 1:200,000:	1,650 frames @ 3 frames/hr 550 hours @ $2.90/hr	1,600	
			$14,200
Color, 1:20,000			
Data Collection:	4,450 frames ÷ 125 frames/125 ft roll 36 rolls @ $227.22/roll + $5 shipping	$8,360	
	1 ea 4-hr mission/2 film rolls 18 missions, 72 hrs @ $100	7,200	
Data Processing:	@ 94¢/ft, 125 ft x 36	4,230	
	Shipping @ $10/roll, x 36	360	
Interpretation/ Analysis @ 1:20,000:	4,450 frames @ 4 frames/hr 1112.5 hrs @ $4.80/hr	5,300	
Compilation @ 1:25,000, Transferred to 1:200,000:	2,225 hrs, @ $2.90	6,500	
			$32,000

Table 5-2: COST PARAMETERS, LEVEL I - FOREST; 34,000 Km^2 AT 1:200,000 (Continued)

maps based on LANDSAT data at this scale would tend to be more accurate overall as the data are acquired at one instant in time, whereas the vagueries of weather in tropical areas may mean that several months might elapse between the dates of the first and last aerial photograph.

Data collection and draft map production time assumes one team working continuously on a project. LANDSAT data is assumed processed in the United States, although it may be feasible in the future to process such data directly in Costa Rica.

If weather and cloud cover problems are experienced similar to those recently encountered in Costa Rica on the demonstration project, then the total time required for data collection and map production may well be twice that shown here, or more. In this event, an approach based on LANDSAT satellite data may not only be the least expensive, it may be the only alternative capable of providing annually or bi-annually updated information for the nation.

It should be specifically noted that total costs incurred and time required to produce 1:200,000 scale maps for a 34,000 km^2 area in Costa Rica will be substantially in excess of that shown here. Costs presented here are variable costs associated with alternative techniques of remote sensing, assuming equally perfect conditions for each alternative. "Fixed" costs, that will be incurred regardless of technique used, are often significantly greater than the variable costs. Accurate prediction of total costs involved in an operational nation wide program should be possible after completion of the currently-planned pilot project.

Aerial photography at scales of 1:20,000 to 1:40,000 may and certainly should be used for many purposes other than the production of 1:200,000 maps at Level I detail. Accordingly, an argument may be made that the cost of data collection and processing, at least, should be spread over several "user agencies" and not included in total in this comparison. The Forestry Department in Costa Rica does, however, have a definite requirement for 1:200,000 scale maps

of this type. If satellite data is unavailable, they must be prepared from aerial photography. In the absence of a firmly stated requirement from another agency for aerial photography of similar type, quality and scale over the same land area, then the total cost of photo data collection and processing must be allocated against this one requirement.

5.1.2 Level III Forest Management Maps, 1:50,000 Scale

As a general rule (and there will be exceptions), LANDSAT data is not sufficiently detailed to be directly used as the sole data source for a Level III forest/vegetation analysis at 1:50,000 scale. Where a requirement exists for 1:50,000 scale mapping at this level of detail, aerial photography of some form must be used. Given an appropriate sampling design, it is often possible to use a mix of satellite and aircraft data in a "multistage sampling" approach. While this will be evaluated during the pilot project stage in Costa Rica, it was beyond the scope of the demonstration experiment.

Level III maps at 1:50,000 scale may be produced equally well and at comparable levels of accuracy through manual interpretation of CIR photography acquired at 1:40,000 scale, color photography at 1:20,000 scale, or panchromatic photography at 1:20,000 scale. The smaller scale is possible with CIR material, as opposed to color, due to its superior haze penetration ability. Similarly, CIR film displays nearly twice the spatial resolution possible with the standard panchromatic Plus-X Aerographic film. If haze is not a problem, then at equal scale and spatial resolution color film will provide substantially more detail and information than panchromatic film. Interpretation and analysis of forest resources at Level III can be performed satisfactorily with 1:20,000 scale panchromatic film, but substantially more interpretation time will be required than when color films are used.

Data collection, processing, interpretation and draft map compilation costs for each of these alternative approaches (CIR, color, and pan) are summarized in Table 5-3. Parameters used to arrive at these costs are given in Table 5-4. As in the Level I comparison, weather is assumed not to be a constraining factor on data collection.

It is immediately evident from these data that color infrared photography at a scale of 1:40,000 would be the preferred choice. Although LANDSAT data was not included here as a "stand-alone" alternative, one point is worth mentioning. If LANDSAT digital data has been collected and processed to produce 1:200,000 scale maps, then the marginal cost to product 1:50,000 scale maps (or for that matter, maps at 1:25,000 scale) would be quite low, typically on the order of $2,000 or less, and they could be produced in a few days time at most. While these maps would not be at Level III detail, they would provide a great deal of information at this scale in a very short period of time at low cost, and would in general be sufficiently detailed to detect and monitor small changes in general forest condition. Supplemental aerial photography would normally be required to identify the change agent or for any in-depth analysis. Such an approach might well be appropriate for consideration in Costa Rica. This will be examined in detail during the pilot project phase.

5.2 Urban Impact Assessment

The principal technical conclusions regarding the effectiveness of remote sensing technology for urban area/urban impact assessment in Costa Rica were:

1. A map at Level I/II detail and 1:50,000 scale is desired by INVU to evaluate the direction and rate of growth of urbanization in the Meseta Central.

	Pan (1:20,000)	CIR (1:40,000)	Color (1:20,000)
Data Collection Costs ($34,000\ Km^2$ area)	$8,100	$8,000	$15,600
Data Processing	2,200	2,000	4,600
Interpretation/Analysis	21,400	5,300	10,700
Compilation [2]	12,900	3,200	12,900
Totals	$44,600	$18,500	$43,800
Data Collection Time	14 Days	9 Days	18 Days
Draft Map Production Time	51 Months (4.3 Years)	13 Months (1.1 Years)	38 Months (3.2 Years)

Table 5-3: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL III FOREST RESOURCE MANAGEMENT DATA IN COSTA RICA AT 1:50,000 SCALE

LANDSAT

Inappropriate as a sole data source at Level III

Pan, 1:20,000

Data Collection:	4450 frames ÷ 225 frames/250 feet roll 20 rolls @ $122.03 + $5 shipping/roll	$2,541	
	1 ea. 4-hour mission/1.5 film rolls 14 missions, 56 hours @ $100	5,600	
Data Processing:	@ 40¢/ft, 250 ft x 14 plus $10 shipping/roll	2,200	
Interpretation/ Analysis @ 1:20,000:	4,450 frames @ 1 frames/hr 4,450 hours @ $4.80 (composite GOCR rate)	21,360	
Compilation @ 1:25,000, Transferred to 1:50,000:	4,450 hrs @ $2.90	12,905	
			$44,600

Table 5-4: COST PARAMETERS, LEVEL III - FOREST; 34,000 Km^2 @ 1:50,000

CIR, 1:40,000			
Data Collection:	1,650 frames ÷ 200 frames/200 ft roll 9 rolls @ $480.51 + $5 shipping/roll 1 ea. 4 hr. mission/film roll 9 missions = 36 hours @ $100	$8,000	
Data Processing:	@ 94¢/ft, 200 ft. x 9 plux calibration and shipping @ $30/roll	2,000	
Interpretation/ Analysis @ 1:40,000:	1,650 frames @ 1.5 frames/hr 1,100 hrs @ $4.80/hr	5,280	
Compilation @ 1:50,000:	1,650 frames @ 1.5 frames hr 1,100 hrs @ $2.90	3,190	
			$18,500
Color, 1:20,000			
Data Collection:	4,450 frames ÷ 125 frames/125 ft roll 36 rolls @ $227.22/roll + $5 shipping 1 ea 4-hr mission/2 film rolls 18 missions, 72 hrs @ $100	$15,600	
Data Processing:	@ 94¢/ft, 125 ft x 36 Shipping @ $10/roll, x 36	4,600	
Interpretation/ Analysis @ 1:20,000:	4,450 frames @ 2 frames/hr 2,225 hrs @ $4.80/hr	10,680	
Compilation @ 1:25,000, Transferred to 1:50,000:	4,450 hrs, @ $2.90	12,905	
			$43,800

Table 5-4: COST PARAMETERS, LEVEL III - FOREST; 34,000 Km^2 @ 1:50,000 (Continued)

2. Annual or bi-annual updates of such maps would be required.
3. A base map at Level III/IV detail and 1:25,000 scale is required by INVU for urban planning and assessment in built-up areas and to evaluate in detail the impact of urban sprawl.
4. Such maps do not require complete revision or updating on an annual or bi-annual basis. Detection of signficant changes at this scale and frequency would be desirable.

The principal urban sector data requirements in Costa Rica are therefore Level I/II maps at a scale of 1:50,000 on an annual or bi-annual basis in urbanizing regions and for Level III/IV maps at a scale of 1:25,000 for use as a planning base, with periodic, but less frequent, updating.

5.2.1 Level I/II Urban Maps, 1:50,000 Scale

Level of detail required is difficult to specify in the urban use case, as both physical size and relative importance of objects of interest vary substantially from the central city to outer fringe areas. In some areas, Level I detail will be sufficient. In others, Level II will be highly desirable. Maps for this purpose and at these levels of detail may be produced from LANDSAT digital data, from color infrared photography at 1:40,000 scale, and from color or panchromatic photography at 1:20,000 scale.

As a general rule, aerial photography is seldom attempted solely for purposes of urban area assessment. A single photograph at a scale of 1:40,000 will cover almost the entire urban area of San Jose, Costa Rica. For this reason, urban studies typically make use of photography collected for other purposes or attempt to obtain their photos through low-cost add-ons to other programs. For cost comparison purposes here, it is assumed that the urban sector bear the full cost of its data collection and processing needs. In practice, this would seldom be the case.

Data collection, processing, interpretation and draft map compilation costs for each of the laternative approaches considered here are summarized in Table 5-5. Parameters used to arrive at these costs are presented in Table 5-6. As with the forest sector calculations, costs of ground operations and similar support costs are not included here. At this level of mapping detail, there is no major difference in average accuracy of the final product, although accuracy of identification may vary from point to point with specific targets.

Based on these data, even with a requirement for annual updating, use of the LANDSAT satellite for urban assessment at 1:50,000 scale would not be cost-effective. Given equal costs for programs based on color and on panchromatic films, the choice would lie with color photography on technical grounds.

If LANDSAT data is being collected and processed for other purposes on a larger area that includes the urban area of interest, such that the urban sector study does not have to bear the minimum collection, processing and analysis costs, then LANDSAT may be a realistic alternative for urban assessment in Costa Rica. Similarly, if regional evaluations of urban impact on scales smaller than 1:50,000 are desired, LANDSAT may have a role to play. Both of these factors will be examined in more detail in the pilot project.

5.2.2 Level III/IV Urban Maps, 1:25,000 Scale

LANDSAT data is not sufficiently detailed to be directly used as the sole data source for Level III/IV mapping in Costa Rica. As with the forest sector, a multistage approach using both satellite and aircraft data may be feasible, although it seems less likely in the urban case. This will be investigated in more detail on the pilot project.

	LANDSAT (Digital)	Pan (1:20,000)	CIR (1:40,000)	Color (1:20,000)
Data Collection Costs (130 Km^2 area)	$200	$300	$700	$400
Data Processing	2,000	100	200	100
Interpretation/Analysis	1,500	300	500	200
Compilation	-	300	300	300
Totals	$3,700	$1,000	$1,700	$1,000
Data Collection Time	Nil	1 Day	1 Day	1 Day
Draft Map Production Time	0.5 Months	2 Months	1.1 Months	1.5 Months

Table 5-5: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL I/II URBAN DATA IN COSTA RICA AT 1:50,000 SCALE

LANDSAT			
Data Collection:	(CCT)	$ 200	
Data Processing:	(Typical Minimum Cost)	2,000	
Interpretation/Analysis/Compilation:		1,500	
			$3,700
Pan, 1:20,000			
Data Collection:	22 frames, 1 ea 250 ft roll @ $122.03 Plus $5 shipping 1 ea 2-hr mission @ $100/hr	$ 327	
Data Processing:	@ 40¢/ft, 250 ft, Plus $10 shipping	110	
Interpretation/ Analysis @ 1:20,000:	22 frames, @ 3 frames/day 59 hrs @ $4.80	283	
Compilation @ 1:25,000, Transferred to 1:50,000:	22 frames @ 2 frames/day 88 hrs @ $2.90	255	
			$1,000

Table 5-6: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL I/II URBAN DATA IN COSTA RICA AT 1:50,000 SCALE

CIR, 1:40,000			
Data Collection:	6 frames, 1 ea 200 ft roll @ $480.51 Plus $5 shipping 1 ea 2-hr mission @ $100/hr	$686	
Data Processing:	@ 94¢/ft, 200 ft plus calibration and shipping @ $30/roll	218	
Interpretation/ Analysis @ 1:40,000:	6 frames @ 0.5 frames/day 96 hrs @ $4.80	461	
Compilation @ 1:50,000:	6 frames @ 0.5 frames/day 96 hrs @ $2.90	278	
			$1,700
Color, 1:20,000			
Data Collection:	22 frames, 1 ea 125 ft roll @ $227.22 Plus $5 shipping 1 ea 2-hr mission @ $100/hr	$432	
Data Processing:	@ 94¢/ft, 125 ft, Plus $10 shipping	128	
Interpretation/ Analysis @ 1:20,000:	22 frames @ 4 frames/day 44 hours @ $4.80	211	
Compilation @ 1:25,000, Transferred to 1:50,000:	22 frames @ 2 frames/day 88 hrs @ $2.90	255	
			$1,000

Table 5-6: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL I/II URBAN DATA IN COSTA RICA AT 1:50,000 SCALE (Continued)

Level III/IV urban maps at 1:25,000 scale may be produced equally well at comparable levels of accuracy through manual interpretation of color infrared, color, and panchromatic photography acquired at a scale of 1:20,000. Comments concerning operational restrictions and relative difficulty of interpretation between film types summarized in Section 5.1.2 apply here as well.

Data collection, processing, interpretation, and draft map compilation costs for these three alternative approaches are summarized in Table 5-7. Cost parameters are presented in Table 5-8. Based on these data, color aerial photography would appear to offer the most cost-effective alternative, primarily due to its superior interpretability for urban purposes.

	Pan (1:20,000)	CIR (1:40,000)	Color (1:20,000)
Data Collection Costs ($130\ Km^2$ area)	$300	$700	$400
Data Processing	100	200	100
Interpretation/Analysis	600	400	400
Compilation	300	300	300
Totals			
Data Collection Time	1 Day	1 Day	1 Day
Draft Map Production Time	1.2 Months	1.0 Month	1.0 Month

Table 5-7: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL III/IV URBAN DATA IN COSTA RICA AT 1:25,000 SCALE

LANDSAT

Inappropriate as a sole data source for this usage

Pan, 1:20,000

Data Collection:	22 frames, 1 ea 250 ft roll @ $122.02 Plus $5 shipping 1 ea 2-hr mission @ $100/hr	$327	
Data Processing:	@ 40¢/ft, 250 ft, Plus $10 Shipping	110	
Interpretation/ Analysis @ 1:20,000:	22 frames @ 1.5 frames/day 117 hrs @ $4.80	562	
Compilation @ 1:25,000:	22 frames @ 2 frames/day 88 hrs @ $2.80	255	
			$1,300

Table 5-8: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL III/IV URBAN DATA IN COSTA RICA AT 1:25,000 SCALE

CIR, 1:20,000			
Data Collection:	22 frames, 1 ea 200 ft roll Plus shipping 1 ea 2-hr mission	$686	
Data Processing:	@ 94¢/ft, 200 ft Plus calibration and shipping	218	
Interpretation/ Analysis @ 1:20,000:	22 frames @ 2 frames/day 88 hrs @ $4.80	422	
Compilation @ 1:25,000:	22 frames @ 2 frames/day 88 hrs @ $2.90	255	
			$1,600
Color, 1:20,000			
Data Collection:	22 frames, 1 ea 125 ft roll @ $227.22 Plus $5 shipping 1 ea 2-hr mission @ $100/hr	$432	
Data Processing:	@ 94¢/ft, 125 ft, Plus $10 shipping	128	
Interpretation/ Analysis @ 1:20,000:	22 frames @ 2 frames/day 88 hrs @ $4.80	422	
Compilation @ 1:25,000:	22 frames @ 2 frames/day 88 hrs @ $2.90	255	
			$1,200

Table 5-8: COMPARISON OF ALTERNATIVE APPROACHES TO PRODUCE LEVEL III/IV URBAN DATA IN COSTA RICA AT 1:25,000 SCALE
(Continued)

6.0 DEMONSTRATION AND WORKSHOP DESCRIPTION

During the week of February 20, 1978 a demonstration of the remote sensing techniques used, products derived, and conclusions reached concerning natural resources survey in Costa Rica was presented in San Jose, Costa Rica. This served to bring the results of the project directly to the individuals involved and then, through interaction between the Costa Rican professionals and RDA personnel, to develop a future course of action regarding the Costa Rican resource problem by better defining actual needs and ways in which remote sensing technology might meet these needs.

The workshop consisted of two major sections. The first day of the two-day program was devoted to presentation of detailed illustrated lectures covering methods and techniques. One segment covered the interpretation of aerial photographs for mapping land uses, techniques of map compilation, and methods of making area measurements of land-use polygons. Another segment dealt with the basic characteristics of the LANDSAT satellite, how it acquires and transmits data, how these data are analyzed with the aid of computers, and specific applications to Costa Rican resource-related problems.

On the second day of the workshop, the participants of the urban land use sector engaged in a "hands-on" interpretation of aerial photographs (see Figure 6-1). Practical experience was gained with natural color and color infrared transparencies, data not heretofore available in Costa Rica. Certain problems were emphasized, such as discerning stages of abandonment of coffee plantations on the city periphery. Costa Rican and RDA participants cooperated in an attempt to resolve problems of application of the classification system to various maps scales and to determine the optimum minimum mapping units which would best serve local needs.

The forestry sector participants discussed data formats, costs, and specific cases for aerial photographic and satellite imagery use. The scale format for the LANDSAT-derived forest cover mapping was discussed, with Costa Rican foresters expressing the

opinion that 1:200,000 scale may be optimum for forest mapping at this time. This, and other points that have been incorporated into the conclusions and recommendations portion of this report, was a valuable result of the demonstration and workshop.

In addition to the workshop, two evening presentations were made, in which a broad overview of remote sensing and the project in Costa Rica was presented to GOCR officials and the general public. These presentations served to broaden public awareness of resource and development problems existing in Costa Rica and provided insight into investigations designed to aid the government in alleviating these problems.

Figure 6-1
Participants at the workshop engaged in photo interpretation and discussion of RDA demonstration products.

APPENDIX A

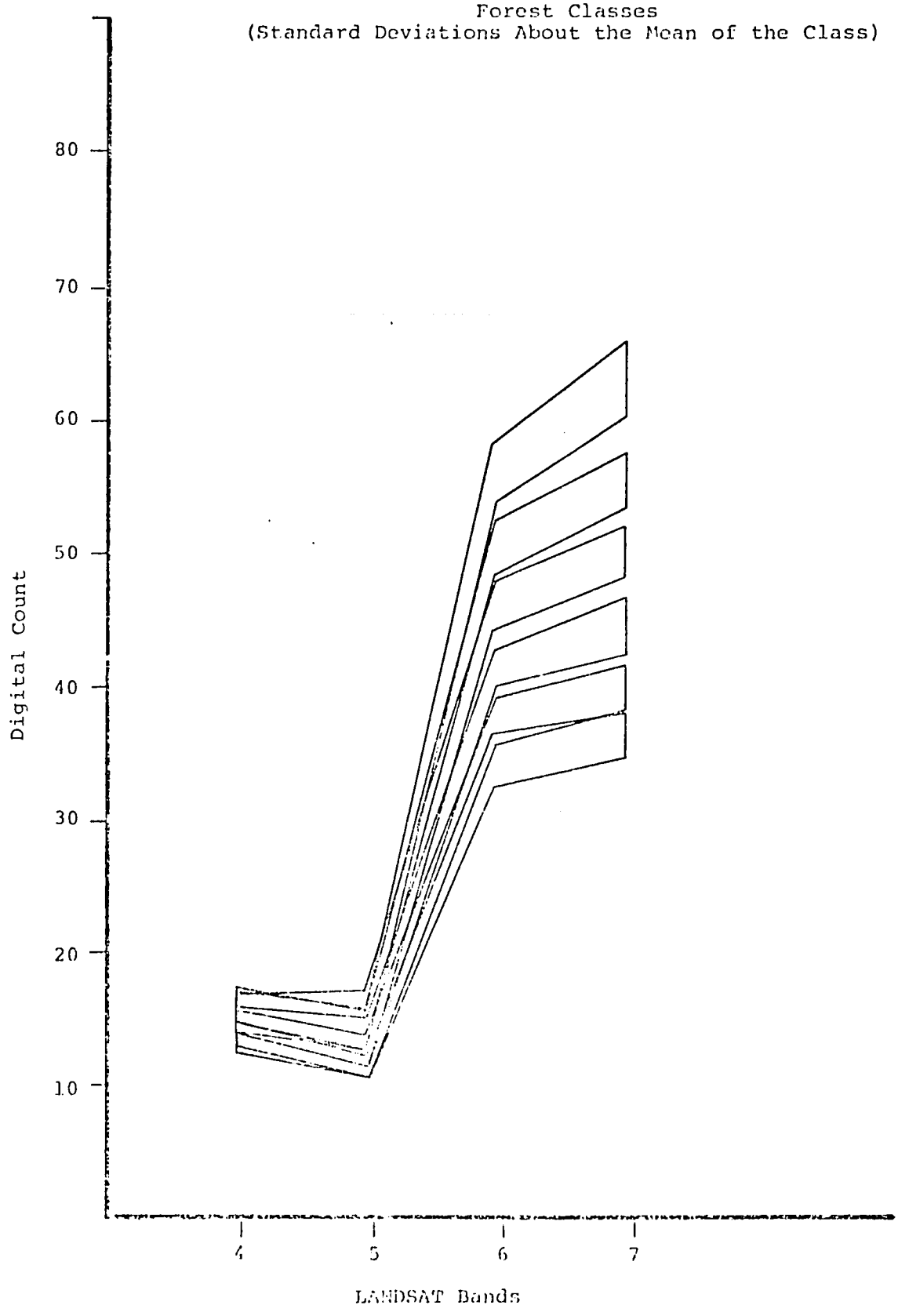
SPECTRAL SIGNATURE DATA

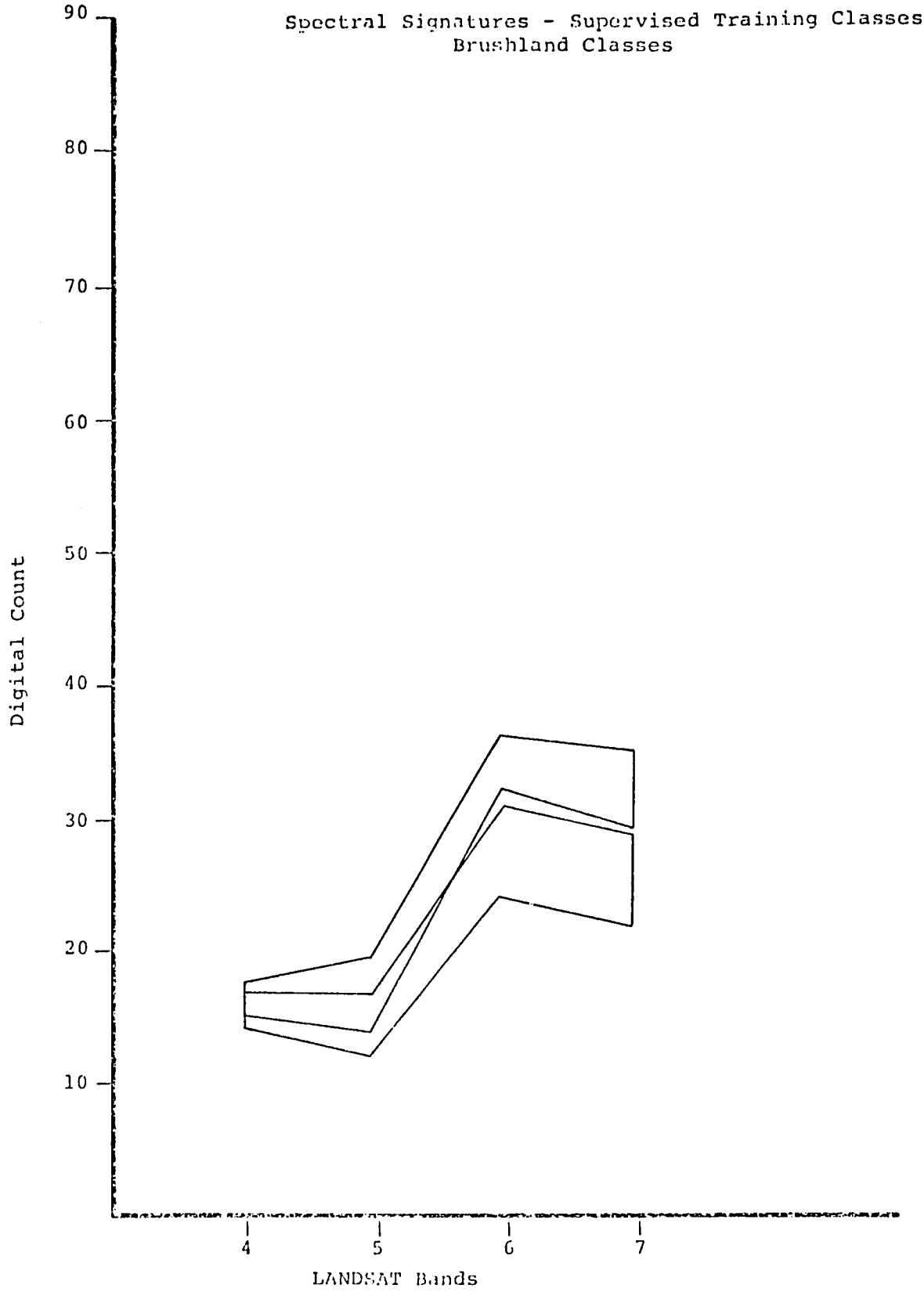
This appendix contains examples of three different types of formats of spectral signature classes used in training and classification of the LANDSAT digital data. The first five figures represent the plotting of the raw digital counts for each of the bands in each training class for the supervised training session. These raw counts correspond to relative energies returned to satellite sensors. The plotting technique that was used was to plot the mean and one standard deviation about each mean and then enclose the one standard deviation points to form an envelope. This allows the user to examine the training classes that he has formulated and spot potential conflicts between classes and also allows him to identify unsupervised training classes of they are taken. Important points to note are that although all of the spectral signature envelopes for the forest classes have varying responses in the infrared, the general signature or shape of the curve is the same. The range classes and brushland classes differ from the forest classes significantly.

The second set of spectral signatures represent only the plotting of the means of each of the four bands for each of the supervised training classes, and then the last chart showing spectral signatures of the unsupervised training classes and how they were interpreted.

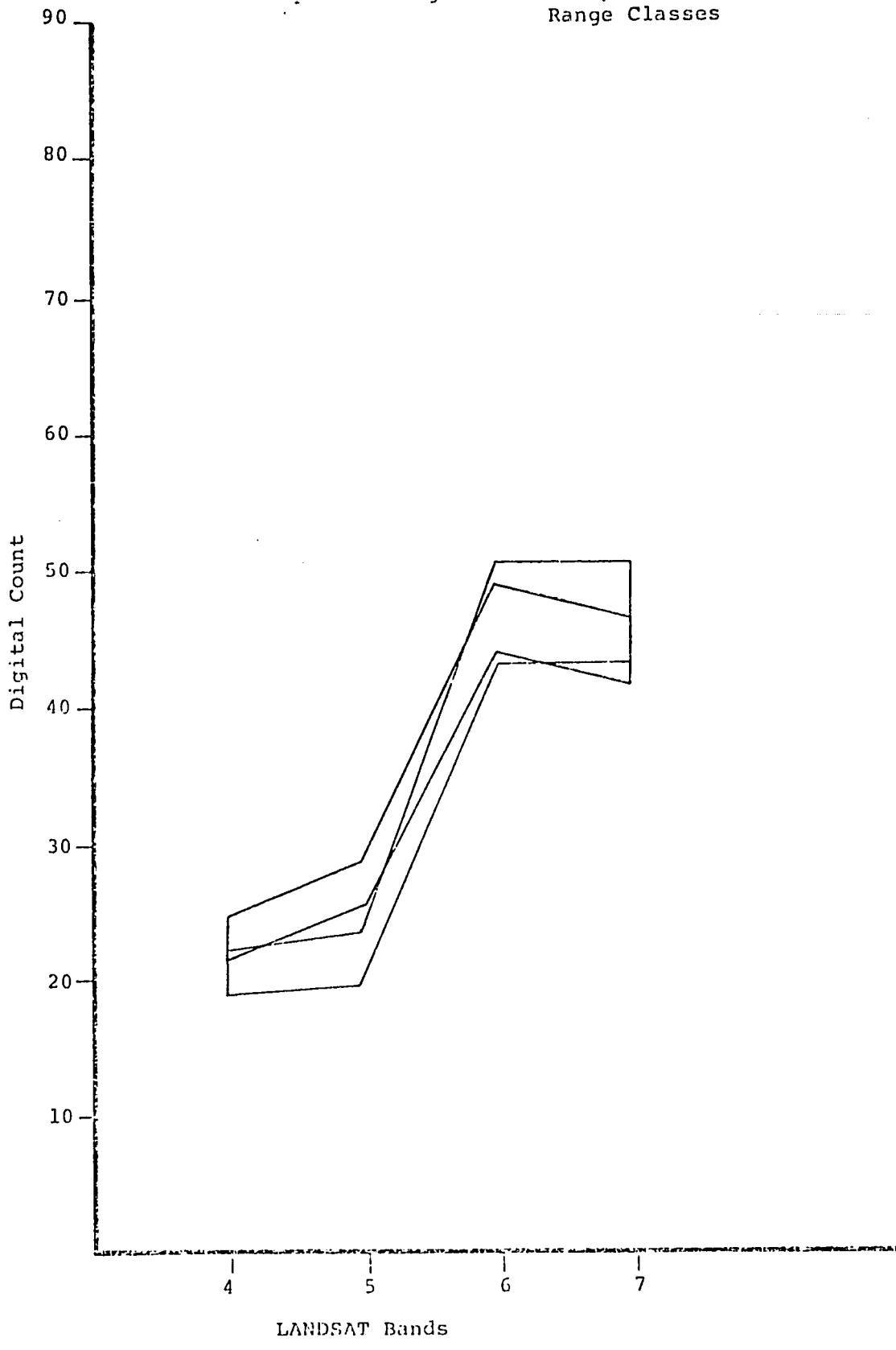
The final set of four graphs were plotted by the computer showing comparisons of classes between bands 2 and 4, bands 1 and 3 and bands 1 and 2. Band 1 and 2 comparison shows that there were tremendous areas of overlap on most of the classes. The difference between bands 1 and 3 are shown to differ more widely and the differences between bands 2 and 4 are shown to differ the greatest. The last two charts show how poorly grouped classes will appear in this type of representation. Groups such as found in these last two charts should signify that poor classes have been drawn and considerable confusion will probably result in the final classification.

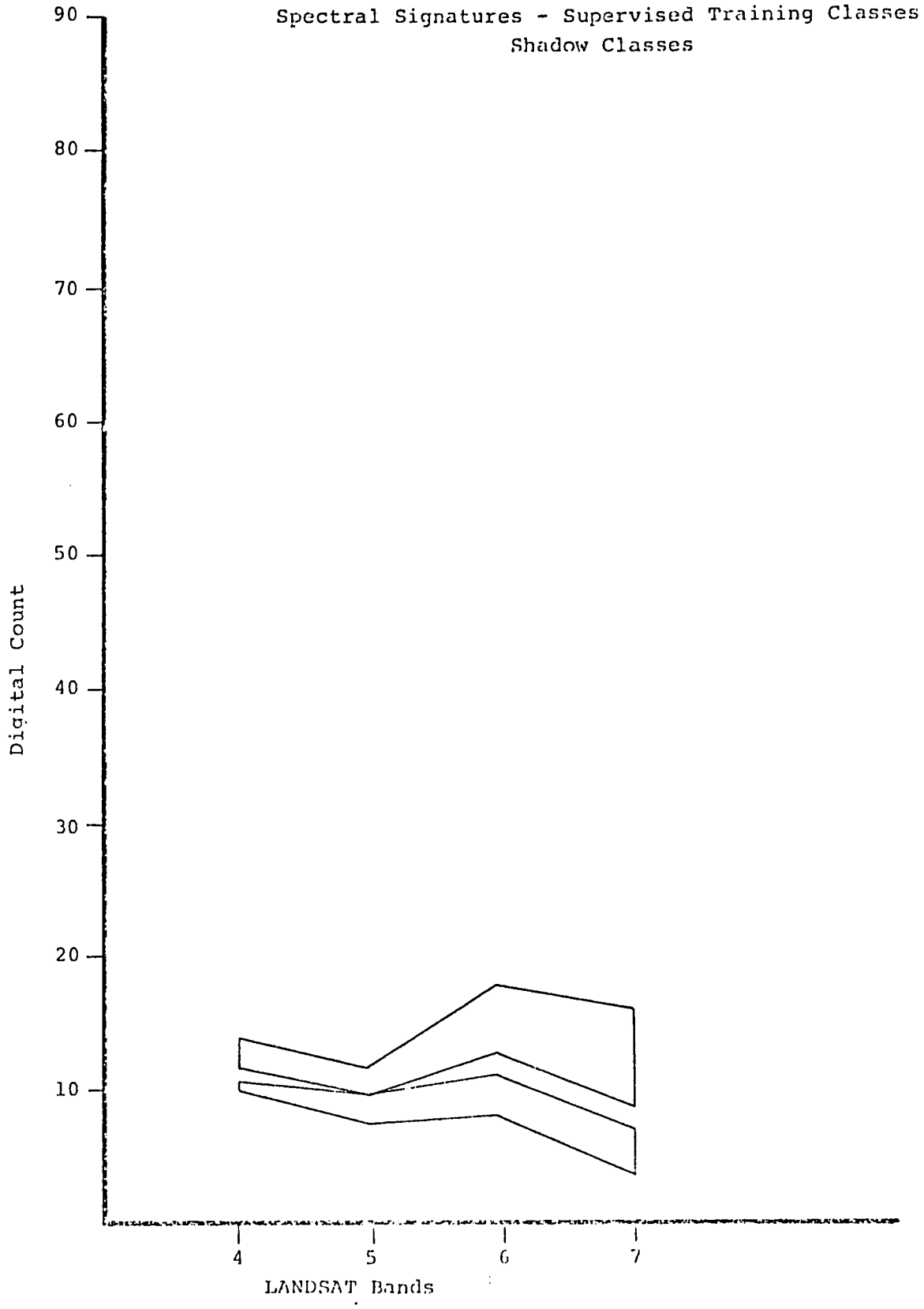
Spectral Signatures - Supervised Training Classes
Forest Classes
(Standard Deviations About the Mean of the Class)



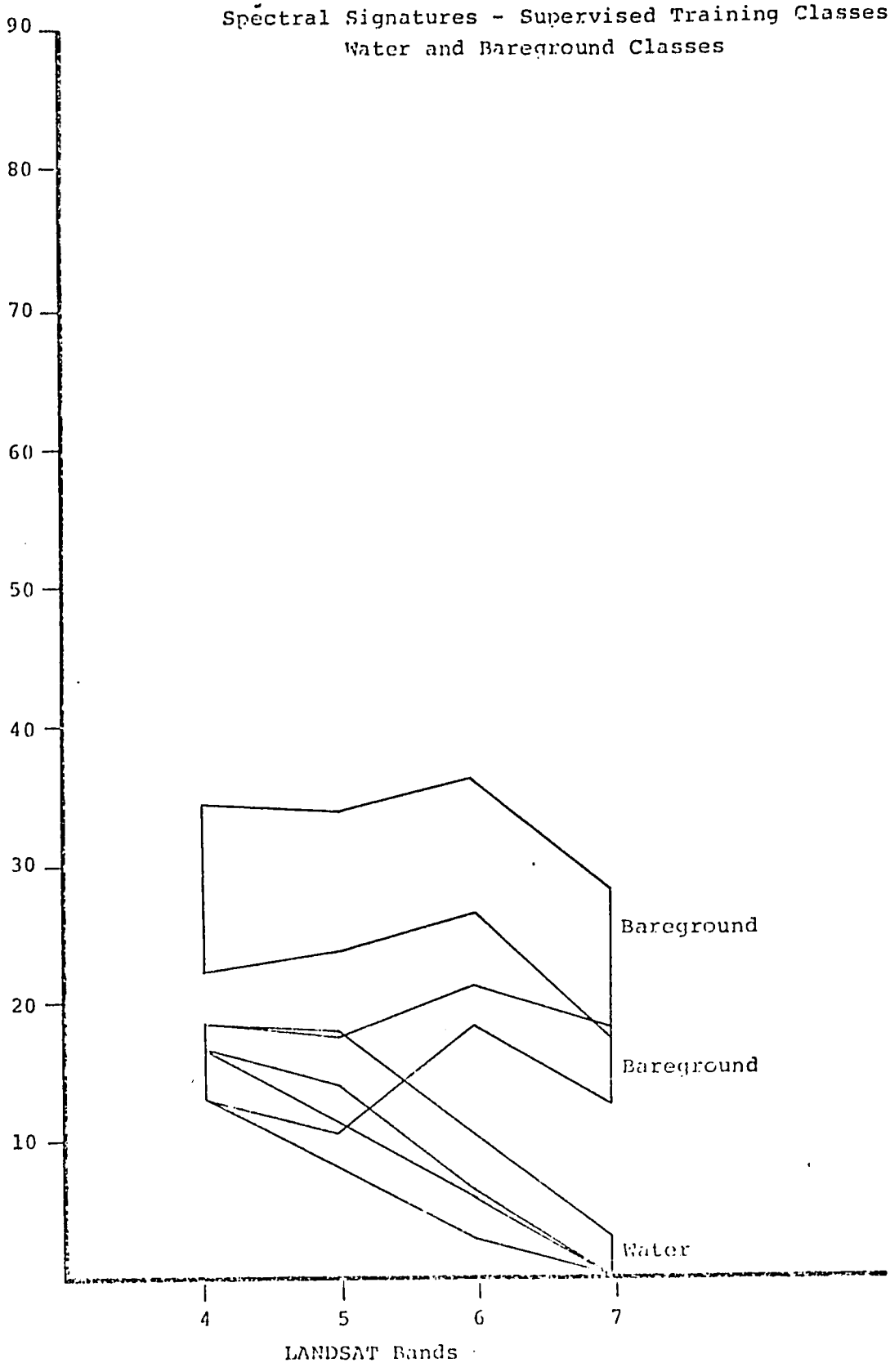

Spectral Signatures - Supervised Training Classes
Brushland Classes
90
80
70
60
50
40
30
20
10
Digital Count
4
5
6
7
LANDSAT Bands

Spectral Signatures - Supervised Training Classes
Range Classes

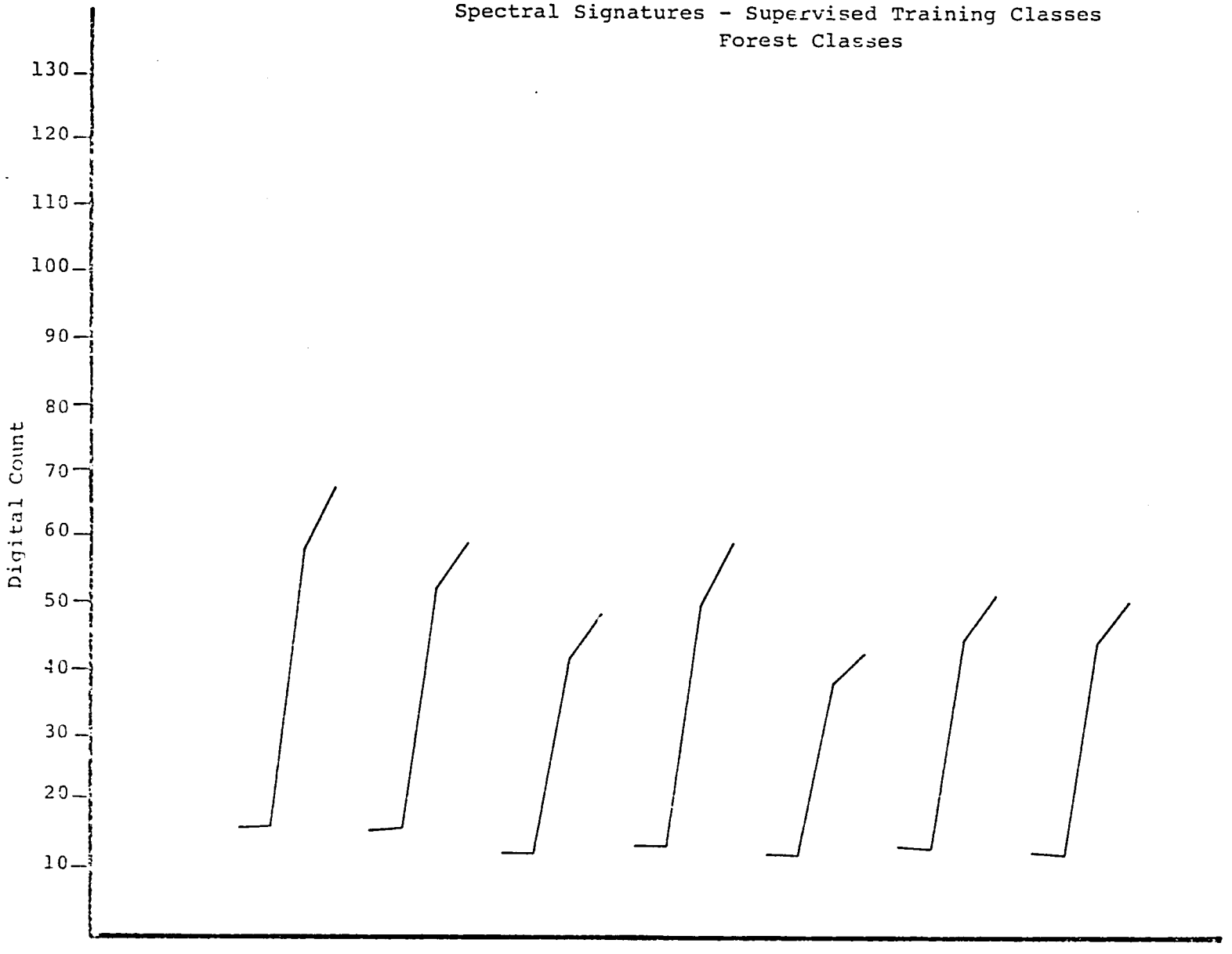



Spectral Signatures - Supervised Training Classes
Shadow Classes
90
80
70
60
50
40
30
20
10
Digital Count
4
5
6
7
LANDSAT Bands

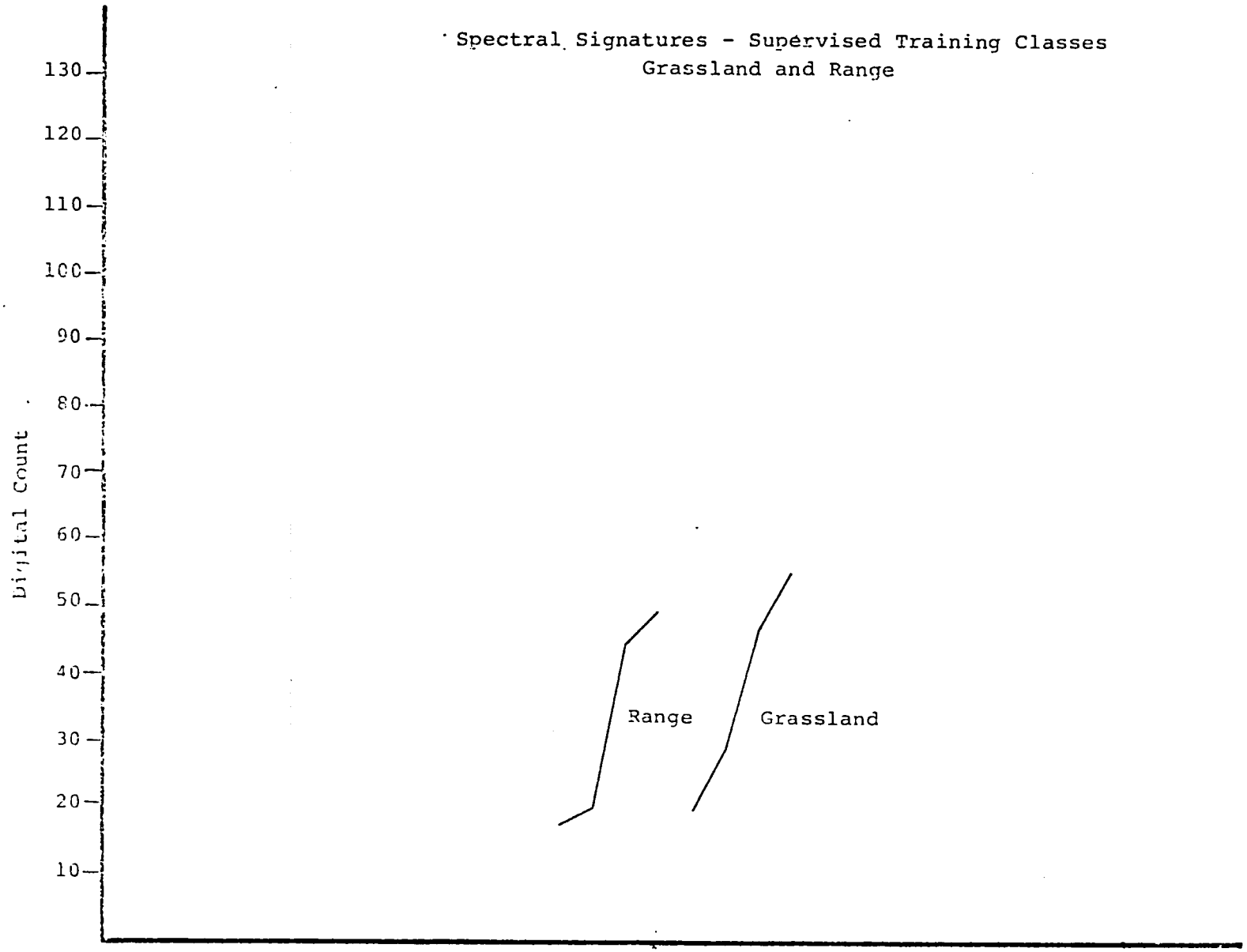
Spectral Signatures - Supervised Training Classes
Water and Bareground Classes



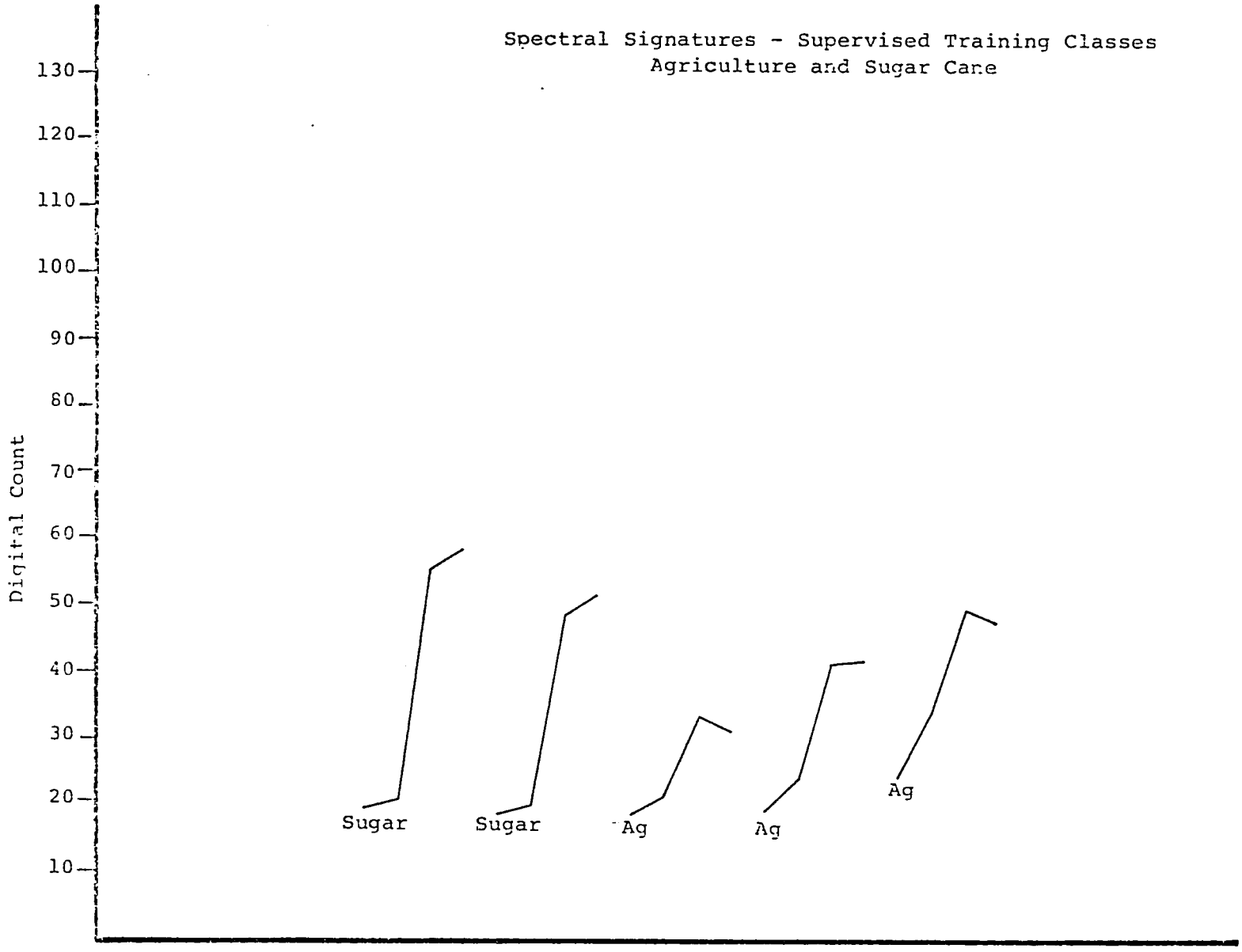
Spectral Signatures - Supervised Training Classes
Forest Classes



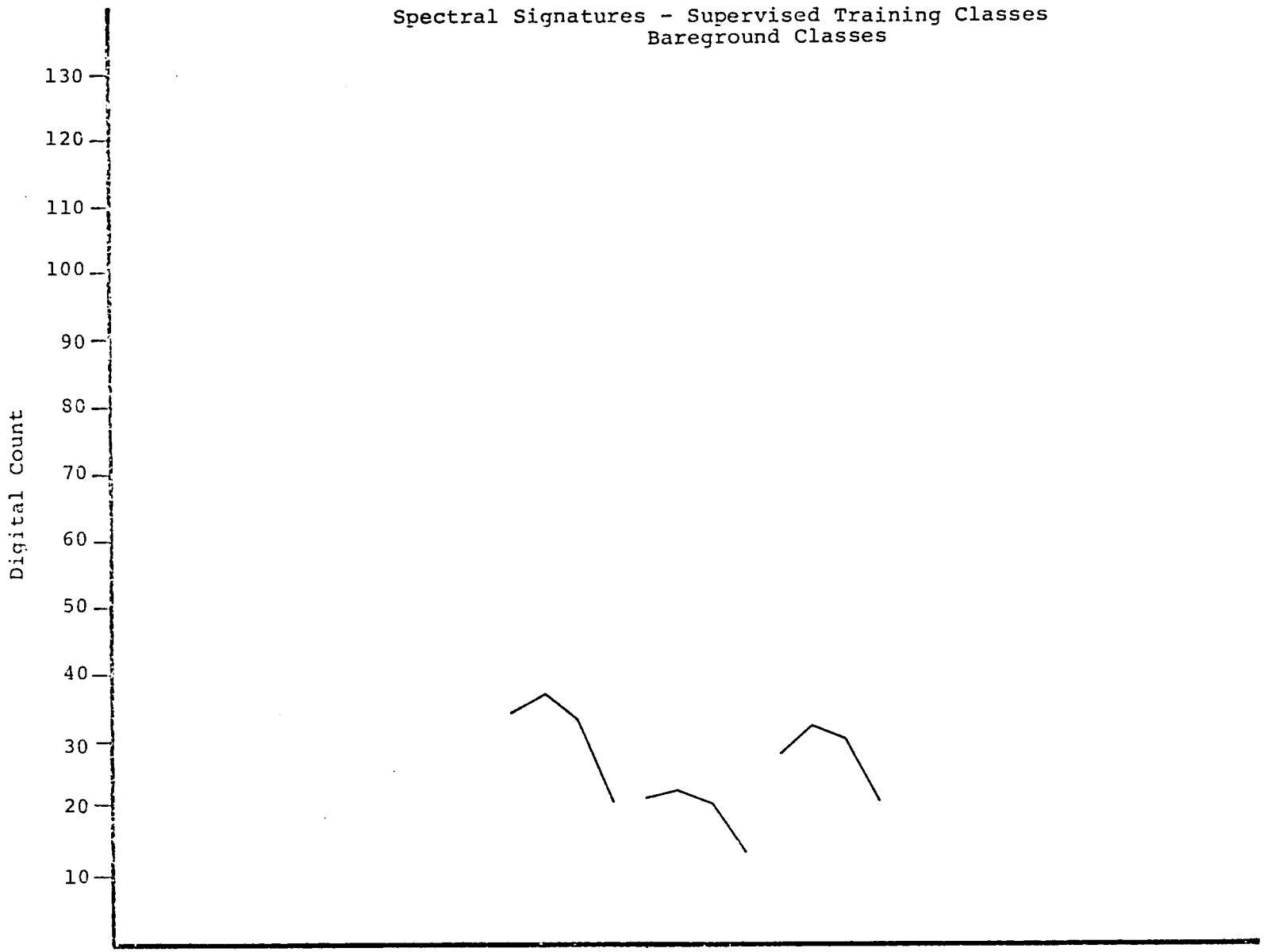
Spectral Signatures - Supervised Training Classes
Grassland and Range

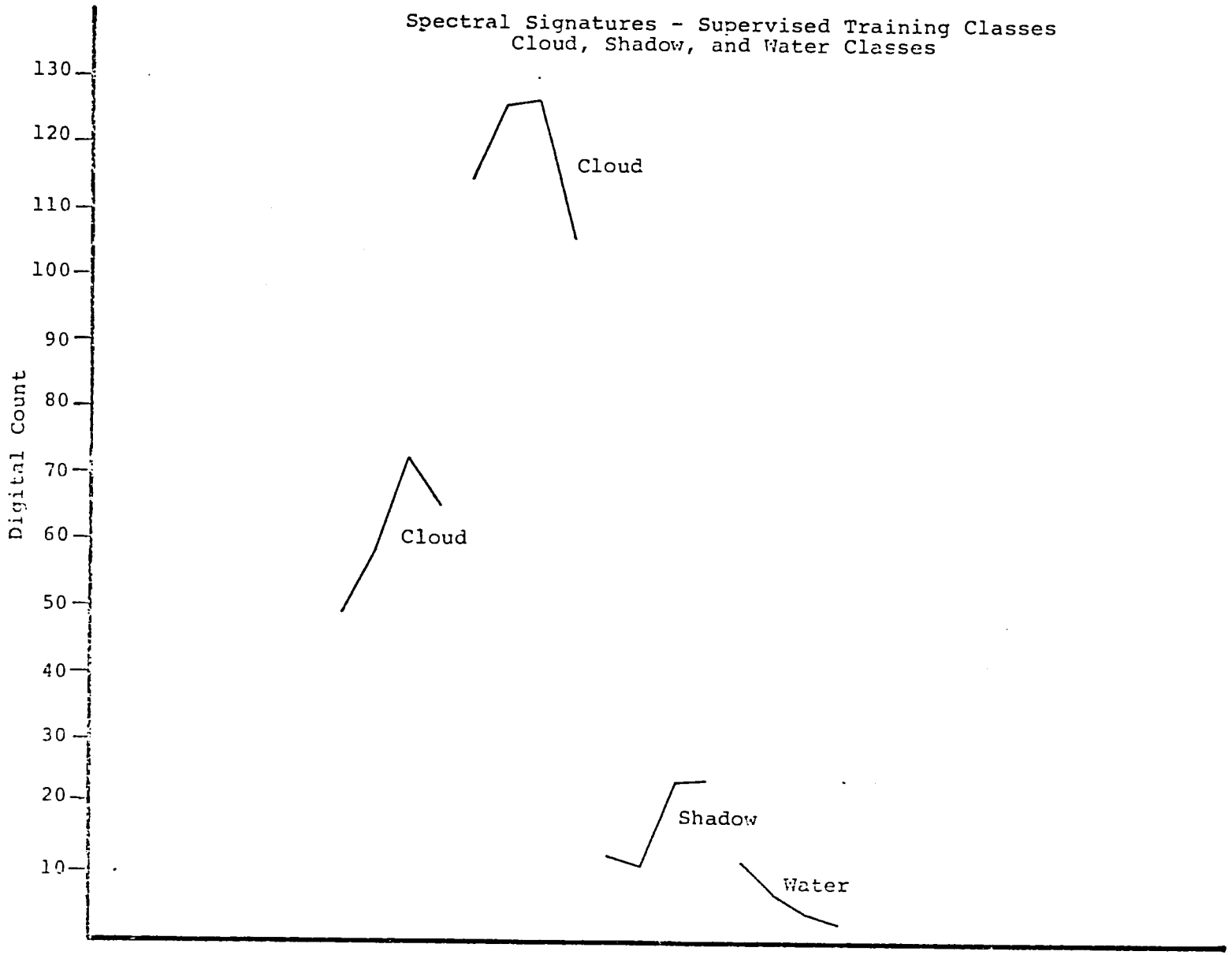


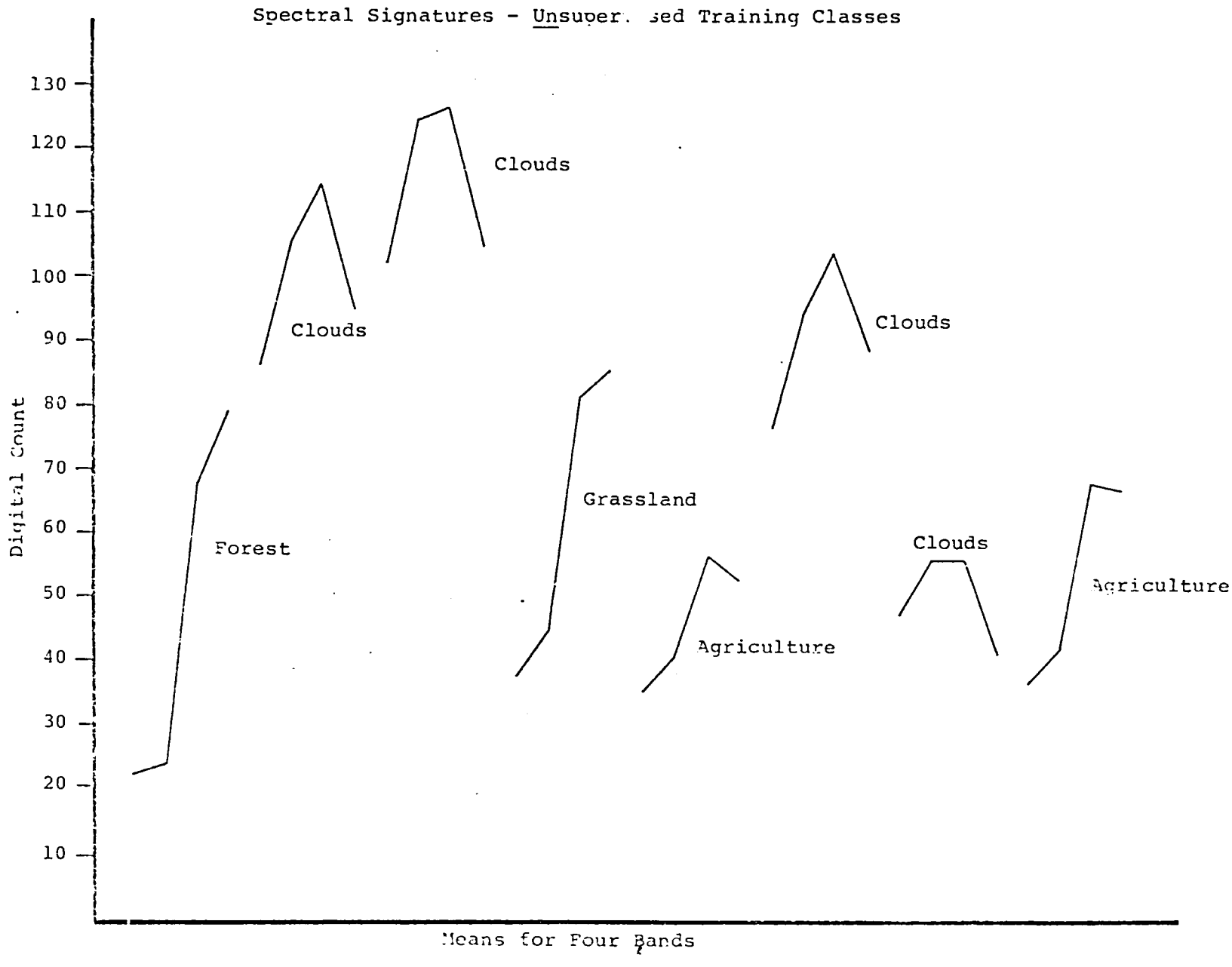
Spectral Signatures - Supervised Training Classes
Agriculture and Sugar Cane



Spectral Signatures - Supervised Training Classes
Bareground Classes




Spectral Signatures - Supervised Training Classes
Cloud, Shadow, and Water Classes
Digital Count
130
120
110
100
90
80
70
60
50
40
30
20
10
Cloud
Cloud
Shadow
Water


Spectral Signatures - Unsuper. sed Training Classes
130
120
110
100
90
80
70
60
50
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Grassland
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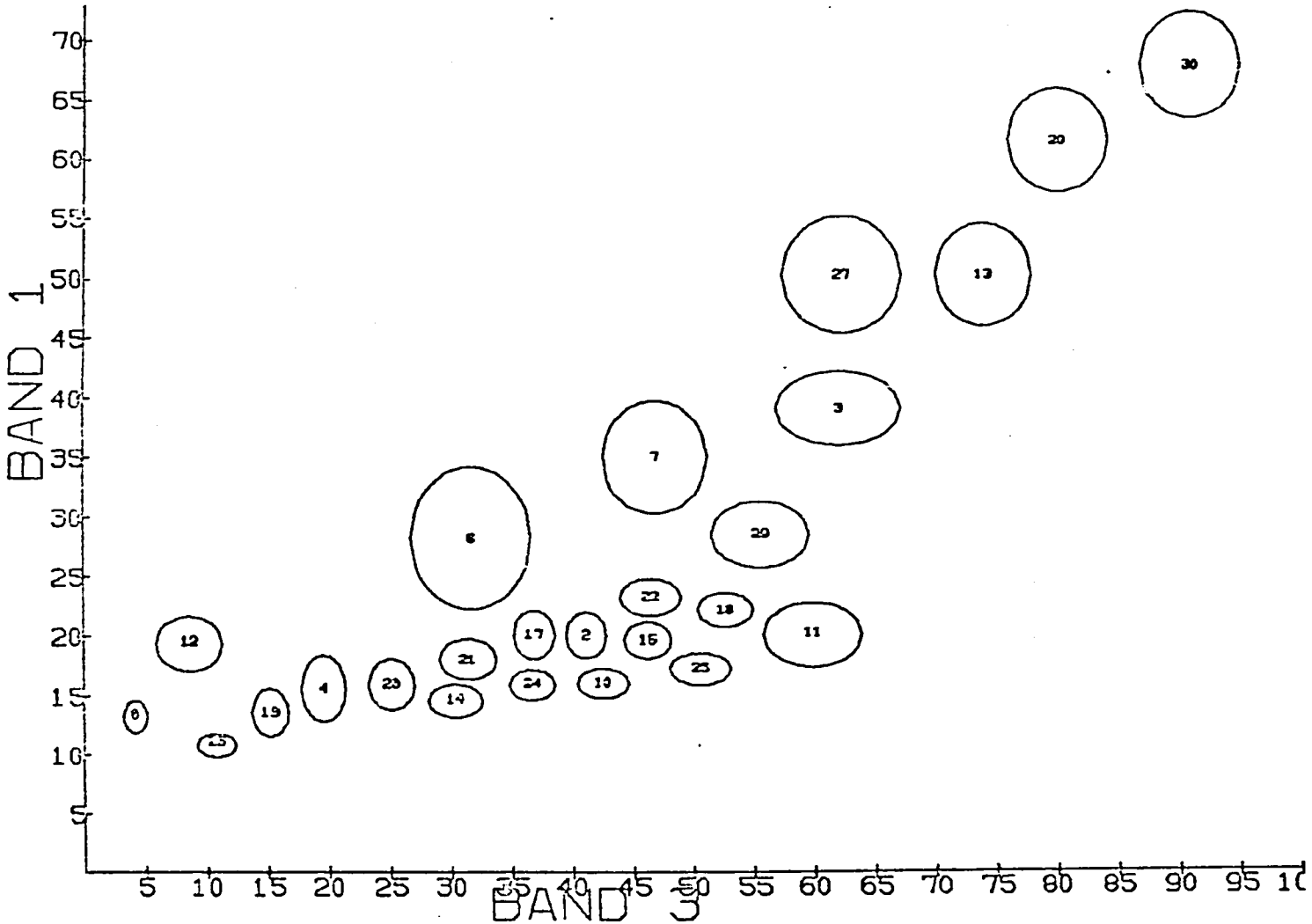
Clouds
Clouds
Agriculture
Means for Four Bands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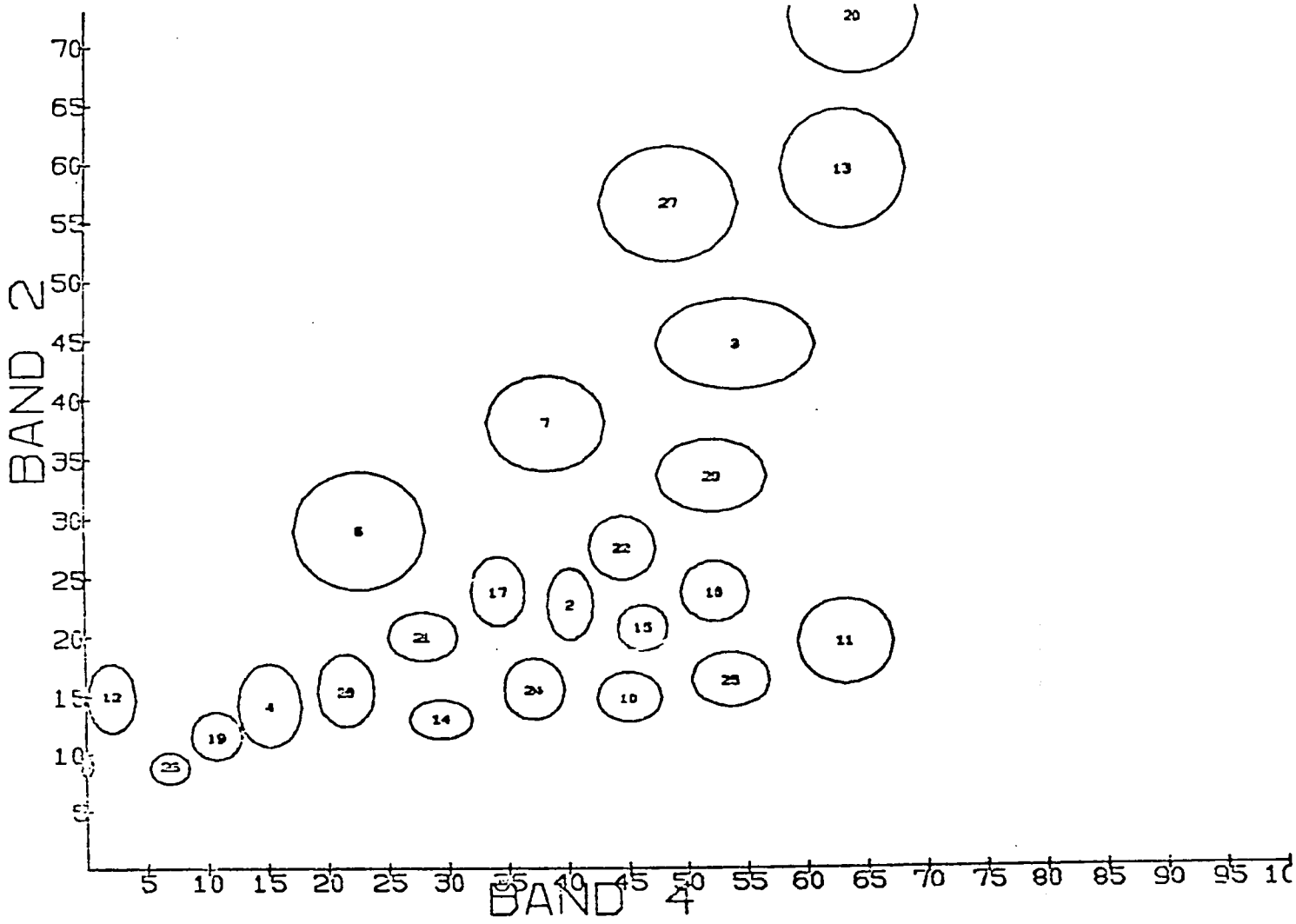
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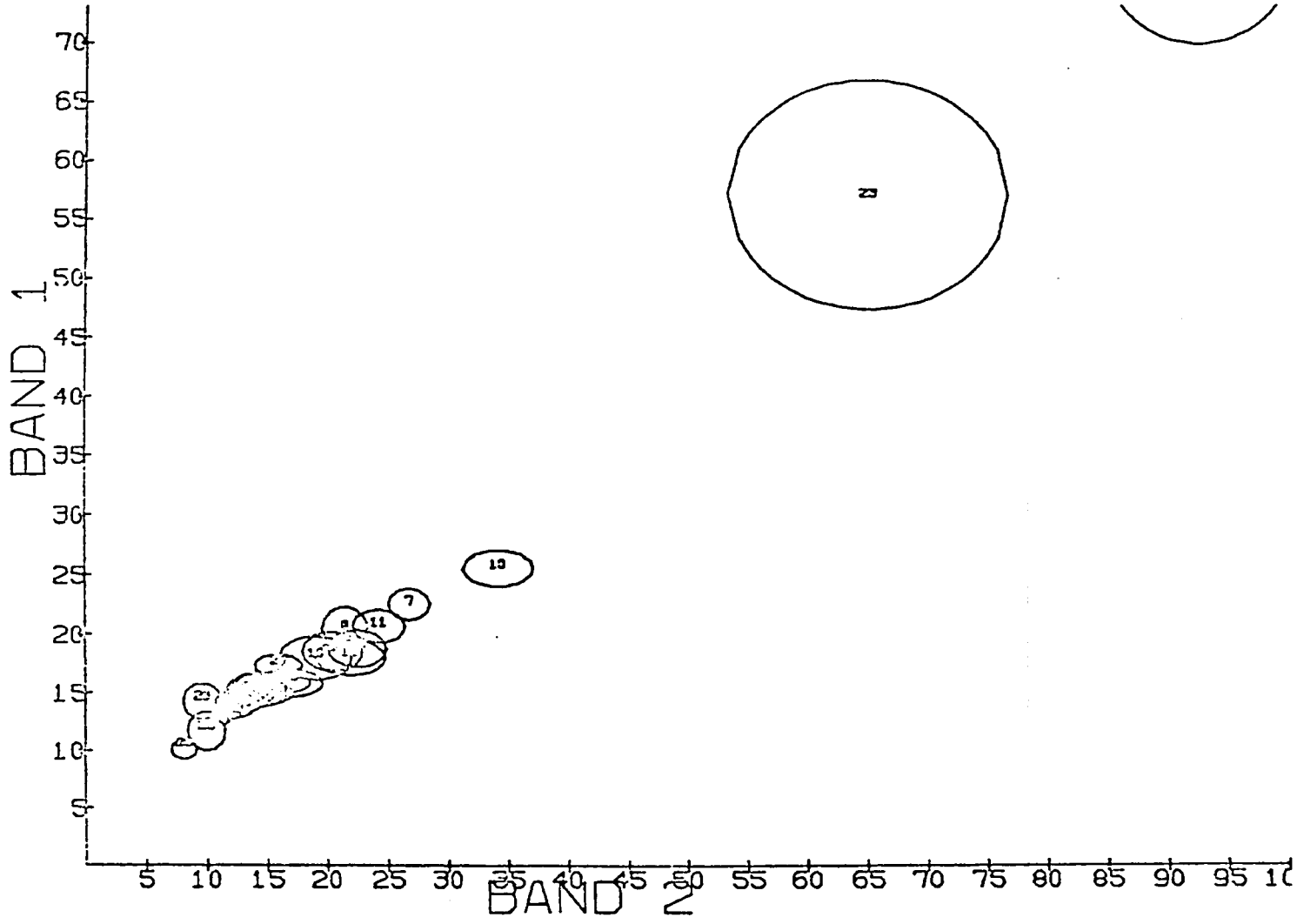
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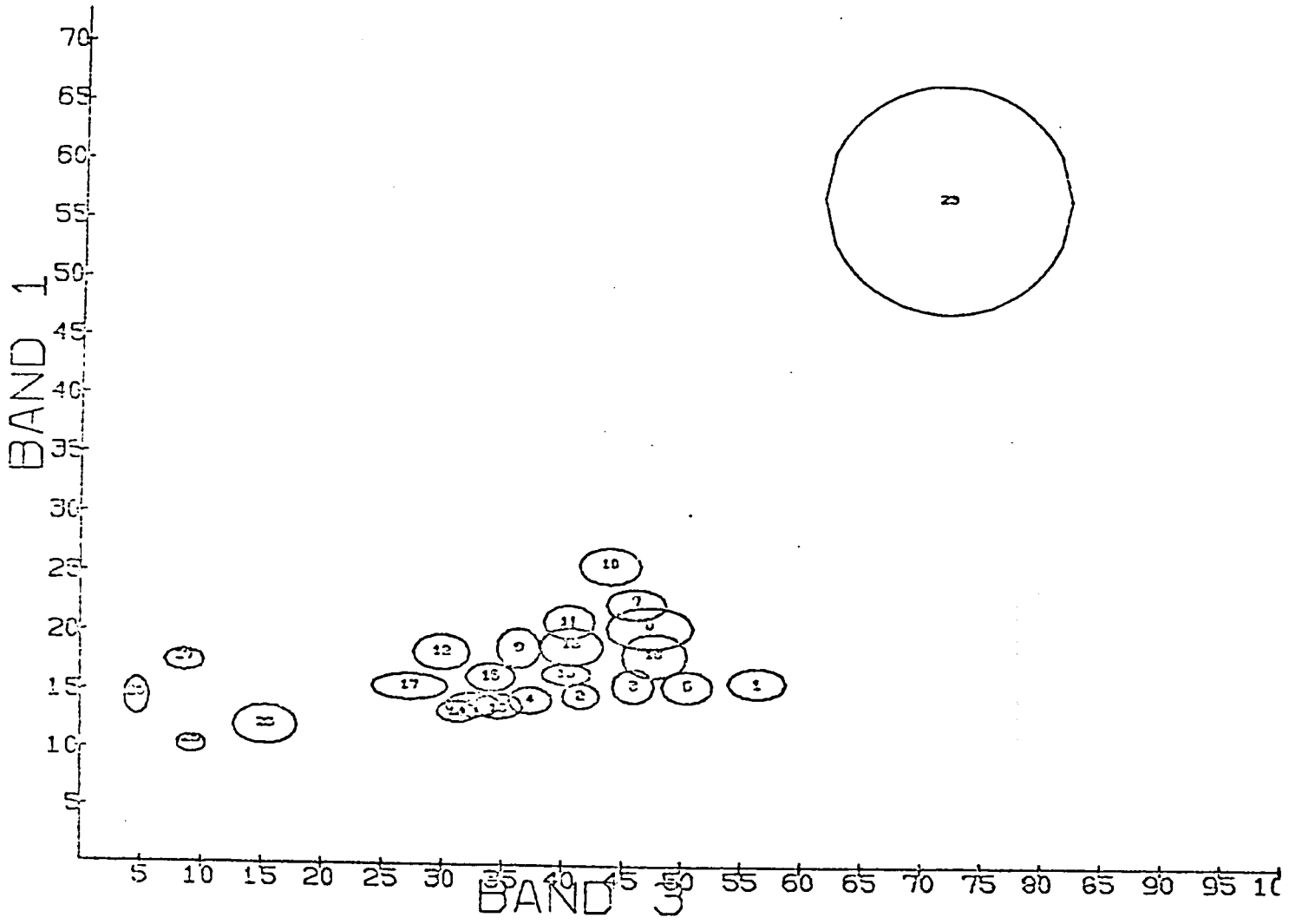
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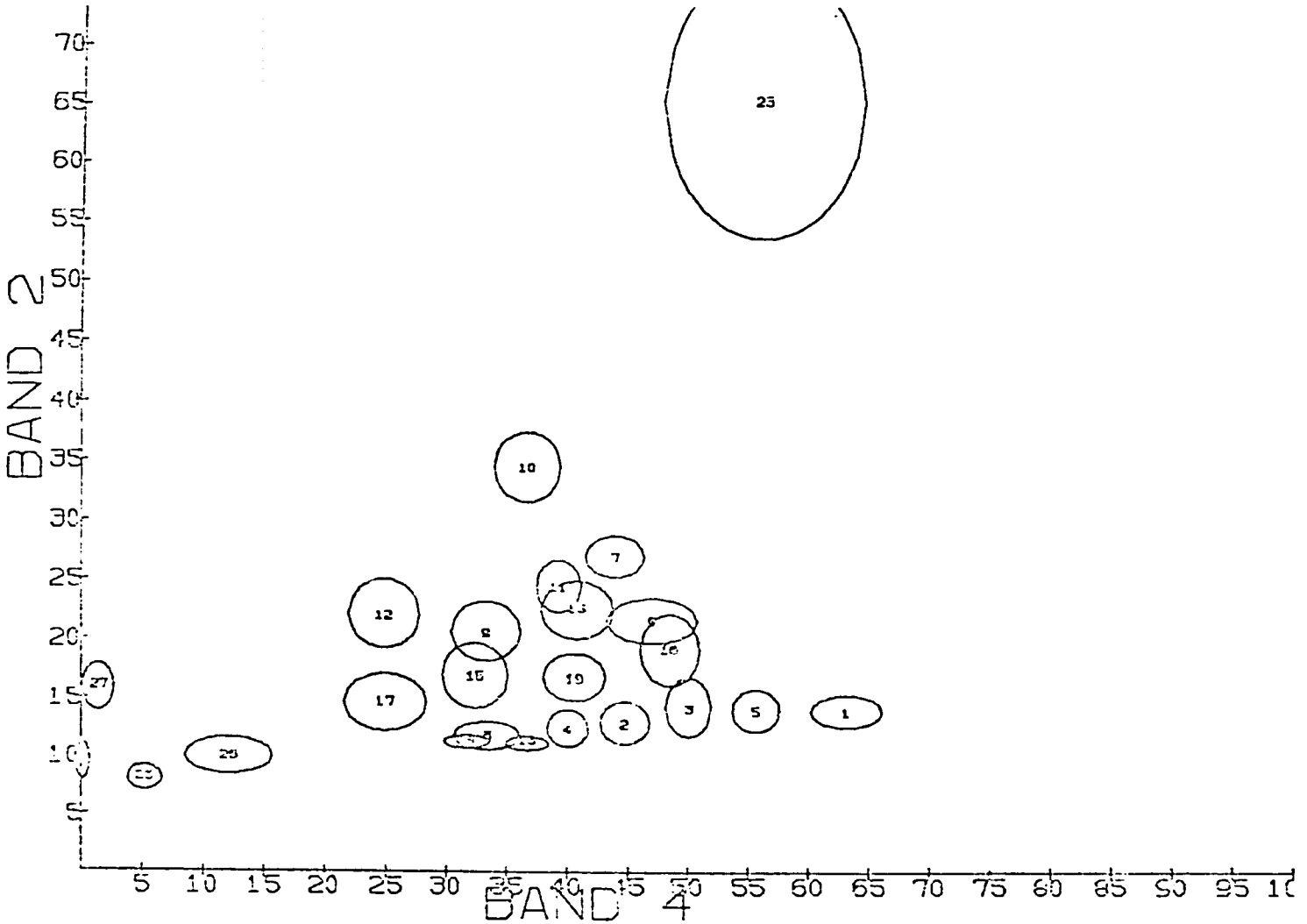
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