ACQUIRING AND USING REMOTE SENSING INFORMATION FOR DEVELOPMENT OF FOREST MANAGEMENT PLANS

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Acquiring and Using Remote Sensing Information for Development of Forest Management Plans

Proyecto BOLFOR
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SECTION I
INTRODUCTION

The BOLFOR Project is designed to reduce degradation of forest, soil, and water resources and to protect the biological diversity of Bolivia's forests, particularly in the Department of Santa Cruz. This project, in collaboration with government institutions, the private sector, and industry, is designed to build Bolivian public and private sector capacity to develop and implement programs for sustainable forest use. The GOB and USAID recognize that these past uncontrolled development measures had a high environmental, economic and social cost and that "sustainable development" practices should become institutionally integrated into the framework of development planning for the forest sector.

Several technical assistance projects undertaken during recent years in the country have provided the basis for improved planning capability by moving towards an integrated or multidisciplinary planning approach. This approach recognizes that the more traditional sector planning approach, although still important, did not properly have a holistic vision of regional planning. Such approaches are the foundation for the PLUS in CORDECRUZ, Zonezig in Pando, and the GOB's program for Ordenamiento Territorial. The purpose of this project is to implement an economically and technically credible process for including environmental considerations alongside the traditional logging extraction criteria used in tropical hardwood harvesting.

Consequently, BOLFOR operates at the concession level with appropriate decision makers responsible for extraction planning and development. The BOLFOR Project recognizes the need to acquire updated and meaningful information associated with physical, biotic and socio-economic aspects, in a practical framework. The collection, analysis and interpretation of this information will result in a rational use of forest concession lands and natural resources in the Department of Santa Cruz. This project component, supported by BOLFOR as a pilot application for the forest industry, will provide a dynamic source of information (e.g., traditional maps at various scales and satellite data) for sustainable forest management.

SECTION II
OBJECTIVES AND STRATEGY

The main objective of this initiative is the acquisition of appropriate spatial information, e.g. maps, to portray the salient features needed for sustainable forest concession management in the Department of Santa Cruz. As written in the Project Design Document this will provide "the information needed to develop ecologically-sound and economically-viable approaches to forest use, as required for eco-certification". The natural forest management component of the project will define the methodology and develop and promote sustainable and commercially viable forest management. The specific project components are listed below:

A. Natural Forest Management Objectives

To sponsor and conduct research which will generate the information needed for rational forest use, forest products certification, and the preservation of biodiversity required for such certification.

- To develop and test natural forest management methods, and incorporate them into comprehensive model forest management plans that meet green certification requirements.

- To develop the capability of Bolivians responsible for the protection and sustainable use of Bolivian forests, and to use this capability in managing and regulating the use of Bolivian forests.

- To extract from research, and to use targeted training and publicity to promote policy and program decisions that are conducive to long-term investment in sustainable forest management, and otherwise to foster the sustainable utilization of tropical forests.

- To assure the scientific evaluation of ecological and forestry interventions, including monitoring the environmental impact of project interventions and selected logging and ancillary practices, as required for forest product certification.

Consequently, BOLFOR recognizes that this Mapping Plan will be used as a significant catalyst to demonstrate how to use varying types of spatial information in conjunction with appropriate field data on habitat types, forest communities, and natural resources at the concession level to meet the above objectives. The BOLFOR Project will undertake a "multistage" data collection process and use these different kinds and scales of information to determine best approaches. This process is to be considered a pilot application that will generate results which will be evaluated on time required to acquire and interpret information, accessibility of information, cost of acquisition, and amount of information. This pilot process will be undertaken for three areas, Lomerío, Moira, and Tarumá. BOLFOR is already conducting extensive field work in these areas, and the acquired information will be linked to this mapping exercise. It is anticipated that the results of this study will be shared with the entire forest

industry, research community and government sector. The mechanisms for accomplishing this process are defined in detail in the following section. A short overview of map scale and methods of data collection are provided to enhance the understanding of these issues for the non-technical audience before that discussion.

SECTION III
MAP SCALE AND SOURCES OF INFORMATION

It is generally recognized that the current map information for Bolivia is out of date and inaccurate. Additionally, necessary information concerning land use and land cover, vegetative communities, habitat type and detailed forest classes are lacking. However, the PLUS project of CORDECRUZ has acquired important Landsat images (tapes and hard copy maps) of the entire Department (19 scenes) and used this information to map current land use.

The level of detail for planning depends to a large extent on the map scales available and used. Small map scales (maps 1:1 million and smaller) show probable natural vegetation and are considered landscape units in the sense that they show the sites on which natural vegetation is assumed to form a relatively time-consistent cover under present climatic regimes, provided the land is not used for other purpose (e.g. human land use practices such as agriculture, timber extraction etc.). This map scale is generally used for national level information, (e.g., Bolivian Forestry Map, geologic map). Intermediate map scales can be defined as ranging from 1:50,000 to 1:250,000. This scale range will be appropriate for regional planning, such as generated by the PLUS project of CORDECRUZ. Large scale maps are defined as ranging from 1:1,000 to 1:50,000. These maps are generally used for site specific planning such as needed for forest concession management. A summary of these relationships is provided in Exhibit 1.

The information used to generate maps comes from several sources. These sources include conventional aerial photography and satellite imagery. Aerial photos are acquired at different scales and with black and white or color films (see Annex A for background discussion). Satellite images are generated from a variety of platforms and sensors (see Annex B for further details). Finally, these information sources and products are used as independent references and commonly incorporated into planning tools such as Geographic Information Systems (GIS), (see Annex C for GIS overview).

Exhibit 1. Area of Analysis, Types of Spatial Information, and Potential Applications

Area of Analysis	Type of Information and Scale	Potential Applications
Department or Province	Landsat TM 1:250,000	Agroecological Zoning and Regional Planning
Province or Concession	Landsat TM 1:100,000 1:50,000 Spot Panchromatic 1:50,000 1:25,000	Ecological mapping Land Capability Concession Demarcation and Mapping Production Estimates Critical Area Management Environmental Assessment
Management Area	Spot Panchromatic 1:25,000 Aerial Photography 1:25,000 1:10,000	Area Frame Sampling Forest Inventory Management Plans Administrative management- Project Coordination Land Capability Mapping- Selective areas

SECTION IV
PROJECT ACTIVITIES RELATED TO MAPPING REQUIREMENTS

This consultant, after discussions with numerous project staff, and local professionals at various institutions, and based on his personal experience, recommends the following activities to provide BOLFOR with necessary mapping tools. These activities are discussed below and a timeline matrix provided in Exhibit 2 represents the BOLFOR Mapping Plan.

A significant initiative for BOLFOR will be the establishment of a GIS Unit. This Unit will be managed by a BOLFOR specialist, with participation from PROMABOSQUE, CDF, and CIMAR, representing a consortium of the forest industry, government and the research communities. The Terms of Reference for this Unit are provided in the annexes.

The benefits of using GIS for forest concession management are summarized in Exhibit 3. The Relationship Between Use of Information, Information Requirements and Potential GIS Uses. This is meant to be used for general illustrative purposes, and is not to be considered a detailed needs assessment. Consideration was also given to the possibility of utilizing one of the existing private consulting firms on a contract basis or CIMAR. However, the results of a quick analysis of each of their attributes and weaknesses (see Exhibit 4) indicated that it is in BOLFOR's interest to develop the technical capability in-house rather than rely on a company or research institution.

A. Document Lessons Learned in Lomerío

BOLFOR has contracted the services of a mapping expert and used satellite imagery from NASA and the Woods Holes Research Institute to portray vegetative types and forest classes in the Lomerío area. Issues related to geometric correction and projection of the Landsat data as used in the field for vegetative mapping apparently resulted in inaccurate maps. A local consulting firm used its GIS to correct the non-georeferenced maps to produce a corrected vegetation map at a scale of 1:100,000. Because there appears to be some unclear issues associated with this exercise, it would prove useful for the BOLFOR project to document this entire process and provide a lessons learned case study to assist future similar efforts. Suggested guidance for similar exercises are available in Annex 4.

B. Contract for New Aerial Photography for the Moira Pilot Area

Part of the project's mandate is to evaluate how to undertake efficient forest management plans. Use of remote sensing data is unquestionably required to accomplish this task. Aerial photos are outdated (1972 time frame) and it is important for the project to get updated coverage of the pilot areas to use for the detailed vegetative and management studies. Consequently, a new set of color aerial photography will be acquired for a portion of the Moira pilot area at several scale, 1:10,000. 1:20,000 and 1:50,000.

Exhibit 2. Implementation Schedule for BOLFOR Mapping and GIS Technical Support

ACTIVITY	1995 Q1	1995 Q2	1995 Q3	1995 Q4	1996 Q1	1996 Q2	1996 Q3	1996 Q4
DOCUMENT LESSONS LEARNED IN LOMERIO								
CONTRACT AERIAL PHOTOGRAPHY								
COMPARE MULTISTAGE INFORMATION								
INVENTORY SATELLITE DATA SOURCES								
ACQUIRE SATELLITE DATA								
CONDUCT ENVIRONMENTAL M&E AND ASSESSMENT WORKSHOP								
MAPPING/GIS EXPERT ARRIVES								
PROCURE GIS HARDWARE AND SOFTWARE*								
INSTALL THE GIS								
IMPLEMENT TRAINING PROGRAM (GIS, Remote sensing, GPS)								
DEVELOP GIS APPLICATIONS								
PROVIDE PROJECT SUPPORT								
UNDERTAKE GIS AWARENESS PROGRAM								

* The GIS unit will be located at a central facility provided by the Camara Forestal and PROMOBOSQUE, under the conditions that they provide space, electricity, airconditioning, and secretarial support. CIMAR and CDF will dedicate one technician each to work within the GIS Unit.

Exhibit 3. The Relationship Between Use of Information. Information Requirements and Potential GIS Uses

Activity	Information Requirements	Potential GIS Uses
Concession Land Use Planning Identify life zones Identify agroecological areas Monitor land use changes Evaluate current land use Prepare concession maps Prioritize management areas Target areas for investments Develop cost-benefit analysis	Hydrogeologic data Water resources Soil characteristics Soil types Topography Vegetative cover Habitat types Protected areas Forest types Critical habitats Extrapolation of key species data Demographic data Land ownership Demarcation of concessions Transportation networks Extraction yield Meteorological data	C Generate thematic maps at various scales for macro and micro planning C Identify critical areas requiring special land management C Model critical area requirements C Identify areas under ecological stress C Map forest inventory data C Provide maps of land use/land cover C Integrate forest extraction potential with reforestation strategy C Provide maps showing management components C Map project status using ecological indicators C Monitor forest cover change over time
Land Suitability/Capability Identify fragile lands Determine best land capability scenarios Select alternative land treatments Develop forest policy strategies		
Biodiversity Planning Identify critical communities, populations and species Target areas of high priority Prioritize management areas Development management plans		
Monitoring and Evaluation Measure administrative progress Identify environmental change indicators		

Exhibit 4. Overview of Existing Organizations in Santa Cruz that Provide Technical Services

Organization	Capabilities	Comments
CIMAR	Equipment pc - DOS HP Pen Plotter Software pc Arc/Info Staff Principal researchers Analysts Students	**Positive** Forestry specialist on staff Knowledge of vegetation and forestry mapping Knowledge of land use planning Continued interest in training and technology transfer **Negative** Outdated equipment Inability to produce high quality products in house Inability to deliver products quickly Handicapped by non-responsive university administration
Geosystems	Equipment pc - DOS Silicon Graphics Workst HP Designjet 650 Trimble GPS Software pc Arc/Info Arc/Info Unix ERDAS - image process Staff GIS analysts Image analysts GPS technicians	**Positive** Proven ability to deliver high quality products HP Designjet provides excellent maps Current state of the art hardware - Unix Excellent software for GIS and image analysis Field experience in GPS **Negative** Probable higher cost Lack of experience in forestry applications
Geoplus	Equipment pc - DOS HP Designjet 650 Genysis GPS Camera and Airplane* Software TNTmips TNTview Staff Analysts	**Positive** Can conduct reasonable(?) aerial photography, plane is local Fly camera with GPS for good ground control Have software that can make geometric corrections **Negative** Current camera format too small (35mm) Skeptical about quality of photo prints and corrected maps No knowledge about pros and cons of mips software

A contract will be issued for this work which will also include production of digital data sets and corresponding maps. Terms of Reference for this work are provided in the annexes.

C. Compare Multistage Information

BOLFOR already possess limited Landsat imagery for the Moira pilot area. The acquisition of the color aerial photography will provide the project with a variety of information at different scales to undertake a comparative analysis. The results of this study will yield valuable information on what each scale and type of information provides, the costs associated with each process, and recommendations for future applications.

D. Inventory Satellite Data Sources

It would be a key contribution for BOLFOR to acquire all useful satellite tapes that have been purchased by the various organizations in Bolivia and internationally for the Department of Santa Cruz. One set of tapes is apparently at CORDECRUZ (series from 1989 and 1990) with several for later years. Geosystems (Santa Cruz) also has some more recent Landsat coverage. These same tapes should also be archived at EarthSat, the original contractor. The Goddard Space Flight Center, NASA has acquired a series of Landsat TM data over the least 5 years. The project should contact all of these parties, ask for complete documentation of the status of these tapes, including current storage media, dates of coverage and ancillary information about classification processing. It is also important to also determine the costs for acquiring copies of the digital data, time needed to accomplish this task, and desired method of requesting such information. A standardized inventory data sheet should be created to acquire this information and a general reference summary of this information needs to be incorporated into the BOLFOR library.

E. Acquire Satellite Data

BOLFOR should acquire copies of all of the above referenced satellite data in a standard format and maintain this data as part of the GIS Unit. The Unit will provide copies of this data to interested users upon receipt of a request for data that details the reasons for wanting this data. Upon review, the appropriate BOLFOR staff will respond to the request.

F. Conduct Environmental Monitoring and Evaluation and Assessment Workshop

The consultant found that the mapping requirements and processes for accomplishing forest management objectives have been well defined. However, a corresponding clear approach for incorporating other resource "environmental" information is still illusive. In the consultants experience with similar M&E efforts, establishment of such practical approaches is difficult, and often not achieved. In the case of this project, the original design identified the need to conduct USAID required environmental assessments (called for in Regulation 16) in addition to ensuring the appropriate information for "eco-certification" is acquired.

There is a growing body of research and literature focusing on landscape mapping, habitat evaluation methodology, and use of key indicator species for establishing impact and assessment techniques. Recently, USAID sponsored a related workshop in Washington. Now is the time for BOLFOR to bring together its multidisciplinary staff to formulate a well designed approach for this component. It is proposed that a consultant be hired to develop background material and then conduct a two day workshop for BOLFOR staff. The objectives would be to develop a concrete approach to mapping processes and M&E approaches by reviewing USAID EA requirements, eco-certification standards BOLFOR forest inventory and management planning, and natural resource research. Although the consultant will be responsible for conducting the workshop, BOLFOR participants will be required to prepare inputs.

G. Mapping/GIS Expert Arrives

Efforts should be made to try and have the mapping/GIS post-doc in the project by August. This will coincide, hopefully, with the finalization of the procurement for the GIS and image processing equipment.

H. Procure GIS and Image Processing Hardware and Software

A configuration for hardware and software is provided in Exhibit 5. This list is based on the following project requirements and factors:

- The project needs to have modern mapping tools available for developing forest management plans.

- Arc/Info is the software of choice because it is already being used within the Ministry of Sustainable Development and the Environment. There is a local vendor with considerable experience who can provide technical support, and there also are other natural resource agencies using this product in the country.

- The PC DOS operating environment is recommended because of its reasonable cost (compared to the Unix version).

- The DOS operating system is preferable, for this particular project, as opposed to Unix because the local knowledge of such software operating systems is more common and learning Unix is adding another dimension of complexity.

- Erdas is recommended for image processing because of its proven record and ability to link to Arc/Info.

In spite of the above factors, this consultant believes there are still some strong reasons to make a larger financial investment and acquire an one seat Unix system. The PC Arc/Info is recommended because of price and "ease" of use of the DOS operating system. If the project wants to operate with current state of the art systems, Unix is the system of choice. The CPU processing speed, particularly for image processing, is so much faster than DOS. This makes all

Exhibit 5. Sample Configuration for PC Arc/Info and Image Processing

For estimate purposes only - not quotation prices

Arc/Info Software		
Basic PC Arc/Info license	3,000	
includes starter kit		
Overlay, Arc Edit, Arc Plot		
Data conversion, Network		
Maintenance Contract (per year)	600	
Erdas Software		
Erdas VGA	3,500	
purchase with Service Upgrade License*	500	
Maintenance Contract (per year)		
PC Hardware		
Pentium with hi resolution color VGA		
Enhanced graphics with 4 Mb VRAM		
Expanded CPU 32Mb		
4x CD Rom , floppy disc, 1 scsci Gig HD	9,000	
Jumbo Colorado Tape Backup		500
HP 1200c desk top color ink jet	2,000	
HP B&W laser jet printer	2,000	
Digitizing table "e"	5,000	
HP Design Jet 650 c Plotter	8,000	
Shipping and Handling	500	
TOTAL (approx.) 35,500		

* recommended so that when Microsoft comes out with windows 95 Erdas can be upgraded to run Erdas Imagin 8.2 in the windows environment. This is needed to increase the processing speed when undertaking extensive image processing.

task processing, including GIS operations, so much easier in terms of time requirements for production. In addition, Unix has become a very standard operation environment for Arc/Info now in many places (there are several systems in Bolivia). It is difficult to predict what will happen with the GIS Unit, but if it begins to provide valuable technical support, there will be an increasing demand for its services. The Unix configuration allows for expansion to a three seat central server system. Exhibit 6 provides a comparative cost estimate for the Unix system.

The Chemonics home office has gained considerable experience in the procurement of several ESRI products. This is a great advantage for BOLFOR, since most of this administrative processing can be accomplished by knowledgeable staff. One issue that will have to be resolved, is whether ESRI Redlands or Geosystems (the local ESRI rep) will actually be handling the procurement. In another Chemonics USAID project in Morocco, ESRI refused to sell to Chemonics under the GSA schedule and required procurement through the local vendor in Morocco. This will be resolved among Chemonics procurement, ESRI, and the USAID contracts office.

I. Install the GIS

BOLFOR will have already negotiated with PROMABOSQUE and the Cámara Forestal and identified a centrally available location for installing the GIS Unit. The equipment will be installed by BOLFOR, with assistance under contract, by Geosystems. Terms of reference for the GIS Unit are presented in Annex D.

J. Implement Training

It is anticipated that the GIS Unit Head will define training needs for the staff. Locally experienced professionals are available through Geosystems to provide practical training. There will be a need to provide training in image processing and GIS. In addition, the entire project would benefit from a special GPS training course that would combine field work with data downloading and GIS mapping. BOLFOR will determine the number of participants for these activities.

K. Develop GIS Applications

This process will occur over the life of the project. It is important for all parties to clearly understand that the implementation of a GIS Unit as proposed here will take time to provide useful products. Much of the effort in the initial first six months will be related to creating base maps, a process requiring digitizing, something which does not happen over night. Most probably, the GIS and image processing analysts will be learning as they work. Also, image processing of satellite data will require significant computer time. The merging of these different data layers and incorporation of field data will, as experience has shown, be slow at first, but improve over time as the analysts gain familiarity with the software.

Exhibit 6. Sample Configuration for Arc/Info Unix and Image Processing

For estimate purposes only - not quotation prices

Arc/Info Software		
Single License with Hardware ** special promotion **		
NETWORK	2,550	
TIN	2,550	
COGO	2,550*	
Arc SCAN (for scanner)	2,550*	
Arc STORM (advanced DBM)	3,000*	
Arc View with avenue (windows)	1,995	
Erdas software	6,000	
Silicon Graphics Hardware		
Indy Workstation		
(includes Arc/Info license)		
133 Mhz, 32 Mb Ram 1.05 Gig internal		
20" color monitor		19,500
Tape back up	1,900	
HP 1200c desk top color ink jet	2,000	
HP B&W laser jet printer	2,000	
Digitizing table "e"	1,600	
HP Design Jet 650 c Plotter	8,000	
Shipping and Handling	500	
TOTAL (approx.) 50,000		

* not needed immediately, can be added later

L. Provide Project Support

As discussed in the description of the GIS Unit, there will be specific project BOLFOR goals to be met. Quarterly review of progress among the Unit and BOLFOR will ensure that goals are being met. This Unit is not intended to be a service support facility for the forest industry nor is it intended to provide non-project applications for the research community. Care must be taken to ensure the integrity of this operation and avoid getting misdirected.

M. Undertake a GIS Awareness Program

Part of the mandate of this Unit will be to provide general information about its activities, accomplishments, and progress to all of the consortium members. This will occur via the quarterly production of the BOLFOR Bulletin. The GIS Unit Head will be responsible for coordinating this product.

SECTION V
CONTACTS

CIMAR	:	Albert Schwiening Gerald Dauber
CORDECRUZ	:	Rodrigo Von Oven Andreas Carstens
Geosystems	:	Herman Lopez
Geoplus	:	Rafael Arias
Noel Kempf Natural History Museum	:	Tim Killeen
PROMABOSQUE	:	Damir Matkovic
Swedforest	:	Lars Marklund Hannes Hoheisel

ANNEX A
ACQUIRING AERIAL PHOTOGRAPHY

Five types of activities would be required as part of this component. These activities are summarized below.

Field Support - Establishing Ground Control Points

The acquisition and interpretation of aerial photography involves some form of ground reference data. This ground control data refers to physical points on the ground whose ground positions are known with respect to a variety of horizontal coordinate systems and/or vertical data. These control points must be identifiable on the ground and in the photograph.

Ground control points are generally established through ground surveying techniques in the form of triangulation, trilateration or traversing. Vertical control is established through the survey techniques of leveling. More recently, the use of the Global Positioning System (GPS) technology is being used in the collection of field surveying information as a faster and accurate process.

The bottom line is that accurate ground control is essential to virtually all photogrammetric operations because the photogrammetric process is only as reliable as the ground control on which they are based.

In this activity, field teams need to conduct ground surveys throughout the concession before the photography is taken. It is anticipated that this work will be undertaken by BOLFOR staff.

Flight Planning

In a location such as Santa Cruz, the local weather patterns can be significantly different from one day to the next. In addition, the sub-tropical climate poses challenges for having preferred minimal cloud cover and low haze conditions. This means that there will be a limited number of days ideal for aerial photography. Consequently, the commercial aerial photography firm will know that actual flights will be dependent on the weather and have to set up a time slot over several days or on call for several weeks to take advantage of weather conditions. Flights are usually scheduled between 10 am and 2 pm for maximum illumination and minimum shadow.

Several geometric aspects must be considered in flight planning. These considerations include (1) the focal length of the camera to be used (2) the camera format size (3) the photo scale to be acquired (4) the amount of territory to be covered (5) the average elevation of the area to be photographed (6) the overlap desired (7) the sidelap desired, and (8) the ground speed of the aircraft to be used.

Flight mission planning includes computations and a flight map that dictate to the crew the (1) flying height above ground from which the photos are taken (2) the location, direction, and number of flight lines to be made over the concession, (3) the time interval between

exposures, (4) the number of exposures on each flight line, and (5) the total number of exposures required to complete coverage for the study area.

Photogrammetric Correction

Following the acquisition of the photography, the film must be processed and then adjusted to incorporate several correction techniques. These correction techniques involve standard photocoordinates that are acquired from the ground control points as well as correction for relief displacement and calculation of elevations of terrain points. These measures are established through a variety of special equipment and computers.

Photointerpretation and Digitization

The aerial photographs contain a detailed record of the features on the ground at the time of photographing. A photo interpreter systematically examines the photos and provides an interpretation of the physical nature of the objects appearing in the photos. In general, the process of interpretation considers the following characteristics: shape, size, pattern, shadow, tone, texture, and site.

The airphoto interpretation process typically involves using a stereoscopic view to provide a three dimensional view of the terrain. This interpretation process must be based on a standard "key" for predefined categories or classification units. For this activity, the following features should be identified: roads - major and rural; hydrography - rivers, streams, lakes, and lagoons; large infrastructure - factories, airports, industry, urban and suburban centers; land cover/land use - forest (delineating appropriate forest types for each concession), pasture, agriculture, wetlands.

Additional basic information that will be required is topography in the form of at minimum for this work 25 meter contour lines. Associated with this elevation data will also be identification of local high and low elevation points with elevation indicators.

The process of digitizing uses modern computer equipment to convert the results of the photointerpretation into digital data sets that correspond to conventional orthophotos. These digital data sets can then be made into maps by using standard and common mapping software and appropriate output devices such as plotters.

Geographic Identification and Labelling

In general the photointerpretation process is independent of the geographic identification and labelling process. In this task, the interpreters will label all major features directly on the map or digital data sheets. This process should include all roads, towns and villages, rivers, streams, waterbodies, major infrastructure, etc.

ANEXO B
IMAGE PROCESSING OF SATELLITE DATA

The use of remote sensing data, i.e., aerial photos and satellite images from Landsat, SPOT and other space platforms is extremely important for forest concession planning as defined by the BOLFOR Project . Often, in developing countries, as is the case in Bolivia, accurate and recent map information and aerial photos are not available or restricted. Consequently, purchase of remote sensing data from public sources such as SPOT Image and Eosat (or equivalent distributors in South America) is essential. The cost of these products can be expensive when acquiring numerous scenes or ground equivalent information (one tape covering 185 square kilometers can cost as much as US$ 3,500). In addition, computer processing of these raw data is required before a useful "map" like product can be generated. In addition, several computer "image processing" systems (e.g. ERDAS) are available for purchase in the same fashion as GIS software. These special image analysis systems are used by special computer analysts to undertake classification techniques.

Image analysis can take several forms and each form or process has an associated expense. There are unsupervised and supervised classification techniques that use special software programs to use the spectral information contained in the basic units of a raster satellite image (pixel) to identify similar categories that correspond to bio-physical characteristics on the earth's surface. It is important to understand that the resolution of a pixel is the smallest detail of information that can be interpreted from the satellite data. Presently, Landsat TM pixel resolution is 30 meters and Spot Panchromatic black and white is 10 meters resolution. In addition, this information is acquired in a fashion that stores the data as pixel units that are raster units, which are blocks of digital information similar to the image of a television screen. This raster information is usually converted to polygon or vector data when producing a map.

The processed data, photo images or computer maps, can be purchased and processed on an as need basis from several vendors (e.g., SPOT Image in Reston, Virginia and EarthSat in Rockville, Maryland) in specific products, with geometric corrections, and photographic or map outputs. In addition, these data can be requested for specific data formats to be directly imported via disk into a GIS.

Existing satellite tape and processed images are potentially available from several sources for the Department of Santa Cruz. First a complete set of Landsat TM scenes covering the entire Department was acquired under the funding of the World Bank for a natural resource and soils survey in the early 1990s. This data was processed into false color images with geometric correction and provided to the Natural Resource Unit at CORDECRUZ. This data should also be available from the contractor, Earthsat Inc., located in the US. In addition, the same satellite images were processed with a different classification process by the German contractor to PLUS, Kischer and Wolf.

Later images are available through an assorted collection of other organizations and institutions. In Santa Cruz, two private sector firms, Geosystems and Geoplus, possess several Landsat and SPOT scenes. CIMAR also has as part of its archive, several additional scenes. In the

United States, the Goddard Space Flight Center of NASA is undertaking a long term tropical forest monitoring project and possesses several recent Landsat TM images. Another project monitoring forest cover at the Woods Hole Research Center has acquired specific images in the department.

It is essential to recognize that each of these sources of satellite data has products at varying scales and with different classifications. For example, the PLUS has generated all thematic information for the Department at 1:250,000 but maintains much of this information at larger scales of 1:100,000 and 1:500,000. The PLUS has also generated GIS data sets of forest cover (with numerous forest types), concession boundaries, and soils.

It is imperative that BOLFOR identify the condition and availability of these data sets. A first priority is to acquire copies of this data, in digital form (tape, disk or CD ROM) and serve as a repository for the user community. This will avoid unnecessary expenditures by different parties for the data. One issue associated with this activity is the need to resolve the copyright restrictions that have existed for this data by the original supplier, Eosat.

Future image processing of these data can be undertaken on a contract basis by vendors, either in Santa Cruz (both Geosystems and Geoplus) or outside the country (United States, Germany, etc.).

ANNEX C
GEOGRAPHIC INFORMATION SYSTEMS

Geographic Information Systems provide data input, storage, manipulation, analysis and display capabilities for geographic, cultural, political, environmental and statistical data in a common spatial framework. The data analyzed are a collection of spatial information (represented by points, lines and areas) and their associated attributes (characteristics of the features which the points, lines, and polygons represent). Examples of point data may include drinking water wells, dams, monitoring stations, and mountain peaks. Lines are commonly used to represent rivers, roads, or contours. Soil classes, crop types, political jurisdictions, and drainage basins are represented as area or polygon data. Some sources of data for GISs include maps, aerial photographs, censuses, field notes, satellite photos and meteorological records.

The advent of sophisticated computers with mass digital data storage devices has facilitated the integration of spatial data analysis, statistics, and computer graphics into comprehensive "turnkey" geographic information systems. GIS technology bridges the disciplines of computer science (e.g., image processing and pattern recognition), information management, cartography, and environmental management. The geographic information system is distinguished from other forms of information systems by its ability to perform spatial analysis.

There are many kinds of GIS turnkey systems. Some overlap exists in terms of their capabilities. Since technology and software are constantly changing, it is probable that vendors will continue to add extra capabilities at reasonable prices in the near future. One significant technology change during the last several years has been the availability of microcomputer-based and Unix-basd GISs. These systems have virtually replaced the more expensive mini and mainframe systems used only a few years ago. Selection of an appropriate GIS software "toolbox" must be linked to clearly defining data analysis needs.

Spatial Data Features

The geographic location of each data item (or "attribute") is a key identifier used to describe and organize data in a GIS. Maintaining the integrity of this spatial descriptor as part of the data base record permits normal data base management system operations and adds the capability to manipulate and analyze data geographically. The concept of data analysis in relation to geographic position is commonly encountered in epidemiological studies.

One frequently used analytical approach is to assign colors or patterns to multiple map themes and overlay them with colored transparencies to reveal spatial relationships. This process of overlaying maps is a major function of a GIS. GISs also provide other analyses, including cross tabulations of data, attribute selections, Boolean combinations, modeling and customized displays.

Geographic data can be represented using either of two formats -- raster/grid or vector/polygon data structures. Raster/grid data refers to attribute values and spatial references tied to specific x, y intersections or grids in space (e.g., latitude/longitude). Fine grid spacing allows high resolution, and good definition of spatial characteristics. Scale is also important in grid spacing since large scale (small area) studies require higher levels of accuracy and finer grid spacing. In contrast, small scale (larger area) studies do not require rasters or grids in such fine detail. Vector/polygon data structures, on the other hand, describe unique lines or forms of geographic features. A lake, for example, can be described by the coordinates which comprise the circumference of the outer lake boundary and can be captured and stored in the GIS as a "tracing" of these features. The geographic attributes of the lake may remain constant even as the resolution of the lake boundary coordinates changes.

Data Input

The data entered into a GIS often include spatial data from maps, remote sensors (aerial photography and satellite imagery), and environmental monitoring. GISs require entry of two distinct types of data: geographic references and attributes. Geographic reference data are the coordinates which describe the location of spatial information. This type of data entry usually occurs via a process known as digitization. A special peripheral device-a digitizer-is used to convert a drawing or map into a digital format. Most GIS projects require a large digitization data input process consuming many man-hours of effort. Attribute data entry (e.g., water quality parametric values) often occurs via key-entry at a terminal, reading a magnetic tape, or downloading from a separate computer system.

Since data which form the GIS data base often come from different sources, and since digitization may be done by staff with varying levels of skill, most GIS data base development efforts involve extensive levels of data validation and quality assurance. An initial and ongoing commitment to data quality is generally rewarded by confidence in the graphical and analytical results of the GIS.

Data Base Management and Data Storage

The characteristic which distinguishes a GIS from other data base management systems and manual map overlay procedures, is the way a GIS stores the spatial data and makes it available for user access and analysis. Derived maps and data sets may become part of the GIS data base in a feedback process that permits future retrieval and display without rerunning the analysis procedure. These map and data layers can be superimposed during analysis to produce various map products with the GIS information display functions. This data generation process requires special spatial analysis and tabulation capabilities provided through the data base management system. Since the analysis and processing limits of each GIS vary from vendor to vendor, the anticipated analytical methods and data base management requirements should be well understood before selecting a particular system.

Efficient data storage organizes the spatial data in a format which permits rapid and accurate updates and corrections to the data base. Data storage refers to how the data formats and structures are supported during data operations. Frequently a data dictionary is used to organize a data base and record information about the geographic and attribute information in the system. Some of the information stored about data bases includes data structures, formats, and access methods. Data dictionaries can be very helpful and important tools, especially for managing active and growing geographic information systems.

Data Manipulation and Analysis

The GIS data base management system provides the ability to query, manipulate, and extract both geographic reference and attribute data. One of the major functions of a GIS is the analysis of multiple layers of data in a selected geographic area. With a GIS, standard statistical manipulations of attribute data are possible, as are Boolean queries of attribute data files, generation of mean and standard deviation for numerical data ranges, and classification of data into mappable units. Other GIS data manipulation and analysis capabilities include querying unique spatial distributions of data and asking questions about data to display the unique spatial arrangements which meet a specific criterion.

Information Display

Information display includes the representation both of raw data and of the results of data manipulation and analysis. Outputs fall into several categories: maps, charts, graphs, surface models, listings, and hybrid representations. The form in which outputs are presented (medium of presentation) also varies, and includes: CRT images (monochrome or color), color slides (from virtual images or directly from graphic bit planes), film plots (print-ready masters), video disk images (requiring digital to analog image conversion), floppy disks of digital image data, microfilm (or "fiche") copies of graphic images, or printed hard copy graphics.

It is important to realize that outputs (as described above) are distinct from spatial analysis. Geographic/spatial analysis of data usually precedes data display, although initial display of "raw" data can serve as a useful hypothesis tester for attribute and/or spatial data analysis. A comprehensive geographic information system supports various computer mapping/graphics peripherals that provide most of the types of outputs described above.

ANNEX D
GUIDELINES FOR USING SATELLITE IMAGERY FOR VEGETATION MAPPING

Introduction

The use of satellite imagery for providing analysis of land cover and land use has evolved tremendously over the last twenty five years (since the first Landsat, ERTS 1, in 1971). Advances in scanner technology, computer technology and continued refinements in algorithm develop for processing spectral data, have made this information readily available to many users. Today, a hi-end PC can out perform, in processing speed and display capabilities, what dedicated turnkey million dollar image processing systems did fifteen years ago.

Interpreting satellite data (for the purposes of this discussion reference is made to Lansat TM and SPOT data) and producing maps has several well recognized steps. These steps are discussed below.

Identification of Study Area

All mapping exercises in the department need to be planned with the IGM 1:50,000 topo sheets. These sheets are available for much of the department. Also, the US Defense Mapping Agency has produced topo maps at 1:100,000, which are available through several sources outside Bolivia. Operational Navigational Charts (ONC) at 1:1 million are very useful when planning a reconnaissance.

The first step is to mark the study area on the above maps and determine coordinates. Image analysis of the satellite data should include standard brightness adjustments, geometric correction and appropriate projection (UTM). Generally, for vegetative studies, image processing uses four bands of spectral data to arrive at a preliminary unsupervised classification, (several algorithms may be used such as principal component, nearest neighbor, etc.). The results are portrayed as a false color composite, with the image analyst assigning specific colors to each "group" of statistically separate spectral classes (e.g., water, barren ground, agriculture). This classification "layer" needs to then be combined with a grid and coordinate reference system as well as cultural map features. These latter features and information should be digitized from the Instituto Geográfico Militar (IGM) base maps. A final "map" product is then generated as a phothoimage (if a film device is used and film development process) or a thermal or inkjet map (from a laser or thermal printer).

Field Inventory

Field workers should carry the above products into the study area and use them as reference together with the standard IGM topo map. If acetate is taped over the maps, one can draw directly on the maps or images, and still have use of the products at a future time. This phase of work should also use GPS to gather ground referenced information. The first step is to locate larger easily recognizable points on the ground that can be seen on the Landsat image. This

would include, waterbodies such as larger ponds or lakes (at least 10 hectares in size), villages, major roads, distinct vegetative associations (e.g., wetlands, or bamboo-palm community). These areas need to be identified on both the IGM topo sheet and Landsat image (use of GPS). All subsequent vegetative mapping and forest inventory need to be conducted with reference to the map reference sheets. Using numbered keys for each location on the map (e.g., pond marked with "1", village marked with "2") with general descriptions as part of the field notes is important for future reference.

Many researchers develop a field survey form for the above process that becomes a useful reference. One must also take into consideration the time of year field work is being conducted and the dates of the satellite imagery. Vegetative differences due to phenology become significant factors in the Landsat spectral information. This means that if you are on the ground during the dry season (low greenness) and are trying to use a wet season (high greenness) image, chances are that there may not be major correlations.

The field investigator can then develop major classifications of forest, vegetation and agriculture. Examples of these classes should be mapped directly on the satellite image while in the field. It is also advisable to maintain a photographic library for these areas by using a 35mm camera with color print film.

Final Image Processing

The field investigator should sit down with the image processor after returning from the field and assist in producing a supervised classification image. The researcher and analyst match identified classification areas on the field maps to the patterns of images on the screen of the image processing system, (the units portrayed on the screen are pixels). By using a cursor, the analyst creates a polygon or window around each classification unit and then creates a signature reference data file for each class. After conducting this process, the image processing system performs another series of algorithm functions to arrive at a "new" revised classification system for the entire study area.

After consultation, the analyst and researcher can agree on color patterns to portray each independent class and a final image product. The result is a supervised, georeferenced land cover land use image product.