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BOLIVIAN DIGITAL GEOGRAPHIC INFORMATION SYSTEM

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I. INTRODUCTION

A. BACKGROUND

Since the advent of the first Landsat satellite, Bolivia has successfully obtained information related to its natural resources. It was soon realized that in order to be able to handle the enormous amounts of data that were being generated,[1] it was necessary to have a system that would readily store, retrieve and manipulate these data. This need was also recognized by the Inter-American Development Bank (IDB), which provided the funds through an agreement for technical cooperation ATN/SF-1812-BO.

Although there are available a number of Geographic Information Systems (GIS) at various stages of development,[6] Bolivia was interested primarily in a technology transfer project together with Purdue/LARS to jointly develop a system that would meet its specific requirements and eventually continue the development and implementation of the system in Bolivia in addition to improving the technical capabilities of its professional staff.

II. CONCEPTUALIZATION AND DESIGN OF THE BOLIVIAN GIS

The first step in the conceptualization of the Bolivian Geographic Information System involved the research and selection of the proper data structure and suitable cartographic map projection, and the development of a method for storing large quantities of data that would satisfy the requirements of a hierarchical system being developed specifically for Bolivia.

A. DATA STRUCTURE

A thorough investigation was carried out in order to select the appropriate data structure to be used in the Bolivian GIS. After analyzing the advantages and disadvantages of the two prevailing data structures, i.e., grid data and polygonal data, it was decided to adopt the grid (cellular) data structure as the primary form of data storage.

Among the advantages of the grid structure are:

1. The simplicity of grids as data structure.[5]

2. In general, software development for almost any application is easier for the cellular approach than for the alternative linked organization.[6]

3. A regular grid has an implicit neighborhood function, and finding a neighbor does not involve search nor extra computer time.[7]

4. The regular geometry allows positional information to be implicit in the data stream.

5. Other variables are easily added.

6. The same set of grid cells are used for several variables.

7. Provides an easily understood system to evaluate suitability for any conceivable land use for which suitability criteria can be defined in terms of the grid cell data stored.[2]

8. Preferred over polygon where there is great complexity of pattern.

9. Simpler when doing your own programming.

10. Processing related to distance is also easily accommodated since the

separation of any pair of points can be computed directly from their storage address.[6]

The main disadvantages of the cellular structure are:

1. Wasteful use of computer storage for spatially sparse data.[6]

2. Errors in estimating perimeter and shape.

3. Cannot be measured with the precision that polygon recording offers.[3]

4. Polygon format is widely used to describe administrative zones, such as counties or census tracts.

5. Use more storage than polygons, hundreds of cells for each polygon area.

6. Restricted to 0-255 values.

accurately together into one whole map.

3. The entire region to be mapped will be covered by a single projection suitable for representation at scales ranging from 1:25,000 to 1:1,000,000.

4. Scale error throughout the projection should be minimized.

5. Maximum error of area must be zero, enabling the use of projection independent algorithms to compute aereal estimates of ground cover.

6. Maximum error of azimuth should be minimized as much as possible.

A number of the most commonly used map projections were examined in the light of the six selection requirements. Combining the five map projections with the six selection requirements the following selection matrix was developed:

Projection	Requirements					
	1	2	3	4	5	6
1. Universal Transverse Mercator (UTM)				x		x
2. Polyconic - Standard	x					
3. Lamber Conformal Conic	x	x	x			x
4. Lamber Zenithal equal area		x	x		x	x
5. Albers Conic equal area	x	x	x	x	x	x

B. CARTOGRAPHIC MAP PROJECTION

Since one of the most important uses of a geographic information system is to determine aereal extent of ground cover/land use information from data stored in a grid cell form, the selection of an equivalent (equal area) map projection becomes imperative. In an equivalent map projection, every data cell (pixel) represents the same area on the earth surface regardless of the cell position in the data base. In contrast, a conformal (equal form) map projection does not meet this requirement.

In order to choose the most suitable map projection for the Bolivian GIS, this projection would have to meet the following six requirements:

1. It should be a projection in widespread use and relatively easy to compute.

2. The chosen projection should be suitable for the production of separate sheets which would fit

The selection matrix shows that the Albers equal-area projection is the most suitable projection for a natural resources data base of Bolivia. The Albers equal-area projection to be used for constructing the GIS for Bolivia would need to cover from 8°S to 24°S latitude, and 58°W to 70°W longitude. Standard parallels of 12°S and 20°S were chosen and the standard meridian of 64°W. The mathematical theory of the Albers map projection is described in detail by Deetz and Adams,[4] and the procedure for calculating the Albers map projection for the Bolivian GIS by Phillips.[8]

C. DATA STORAGE

The Bolivian hierarchical system consists basically of a four-level 16-element grid cell structure that permits ready access to information at local, departmental (regional) and national levels of detail. The entire geo-referenced plane (hypothetical 1,300 kilometer x 1,500 kilometer plane) was divided into quadrangles of 1,000 x 1,000 cells. Each of these quadrangles contains

16,000,000 bytes of data and can be stored in a single 800 bpi (bytes per inch) magnetic tape.

The first level of storage (input level) consists of 50 meter x 50 meter (0.25 hectares) cells. Bolivia is covered by 492 quadrangles of 50 kilometers x 50 kilometers each (Figure 1) containing a total of $7,872 \times 10^6$ bytes of data.

The second level (local) is constructed by aggregating the information of the first level into 100 meter x 100 meter (1 hectare) cells forming 137 quadrangles of 100 kilometers x 100 kilometers (Figure 2), with a total of $2,192 \times 10^6$ bytes of data.

The third level (departmental) could be created from either levels 1 or 2 and consists of a 500 meter x 500 meter (25 hectares) grid. The whole country is covered by 9 quadrangles (Figure 3) providing 144×10^6 bytes of data.

The fourth level (national) could be constructed from levels 2 or 3 and would consist of 1000 meter x 1000 meter (100 hectares) cells. Bolivia would be covered by a single 1,300 kilometer x 1,500 kilometer quadrangle (Figure 4) storing 31×10^6 bytes of data. Table 1 shows the hierarchical data base structure using four different levels of storage.

The digital Geographic Information System conceptualized and designed for Bolivia basically consists of five major subsystems: 1) Input subsystem, 2) Data base subsystem, 3) Management subsystem, 4) Modeling or analysis subsystem and 5) Output subsystem. Figure 5 illustrates a simplified schematic configuration of the Bolivian GIS.

D. INPUT SUBSYSTEM

It is through this subsystem that geo-referenced (spatial data contained in a standard map format) information is converted to a format suitable for storage, management and analysis in a digital computer. This process is generally known as digitization. In order to input the different data base elements (soils, land use, geologic maps, etc.) into the GIS, one has to first of all convert these maps into digitized grid files.

The first step in the process of map digitization involves the map preparation activity. That is, the maps to be digitized should be carefully examined in order to insure that all boundaries (polygons) are closed and that all thematic units (areas enclosed by boundaries) are properly named or numbered. Once this process is completed, the existing thematic units should be numbered according to a previously selected "fill character" (ranging in value from 0 to 255), which corresponds to the "thematic code" assigned to each of the units.

The next step involves the segmentation of the polygon boundaries into discrete arcs, each one having "beginning" and "ending" nodes, and "left area" and "right area" designations. These left and right area designations should correspond to the numerical values assigned to the thematic units. These concepts are illustrated in Figure 6.

In selecting left and right areas, or in other words, the direction of digitization (clockwise/counterclockwise), care should be taken in estimating the size and assessing the significance of the units; small and important units should always be digitized clockwise, so that the left area is assigned to the outside of the unit and the right area assigned to the inside as illustrated in Figure 6.

The input subsystem of the Bolivian GIS consists of (a) a Map Input capability and (b) an Attribute Input capability.

(a) Basically the Map Input includes the following processes:

    1) Digitization
    2) Editing
    3) Coordinate transformation
    4) Rasterization

1) Map digitization is the process by which maps are transformed into computerized form. That is, closed boundary lines (lines enclosing thematic units), linear features (rivers, roads, etc.) and point data (intersection of geographic coordinates, mine locations, etc.) are converted into a series of numerical values suitable for computer processing.

2) In order to determine the quality of the digitized maps, the digitized arcs, linear and point features are displayed for visual inspection. During the processing step, the digitized arc files can be edited, i.e., arcs are closed, added, or deleted. This process can be accomplished either through an automatic arc closure routine or by

means of manual editing.

3) The relative numerical values resulting from the digitization process are first converted into a geographic coordinate system (latitude and longitude), and subsequently these coordinates are transformed to a preselected map projection. The Albers Equal Area Conical Projection was selected for the Bolivian GIS.

4) The last process in the Map Input subsystem consists of the rasterization step. During this process the map units are filled-in with pixels (cells) according to a predefined grid, and they are labeled with an identifier (fill character). Figure 7 illustrates the different steps involved in the conversion of a polygonal file into a rasterized (gridded or cellular) file.

(b) The Bolivian GIS Input Subsystem also includes a capability for inputting descriptive (attribute) information related to the resource map data items. This information is simply entered (keyed-in) using a terminal keyboard.

E. DATA BASE SUBSYSTEM

The definition of "information" from a system's viewpoint can be given by the following simple conceptual equation:

Data + Processing = Information

The relationship between this concept of "information" and the basic components of a digital GIS (shown in Figure 5) is as follows:

of a series of layers or channels of digitized maps and/or multispectral scanner (MSS) data. These digitized maps and/or digital MSS data sets are stored in the computer in the form of geo-coded or spatially referenced image planes. Figure 8 shows the concept of an Image Plane Data Base.

The Attribute Data Base is composed of records that contain descriptive information related to the Image Plane Data Base. These records are stored in a linked list format. Figure 9 shows the hierarchical structure of the Bolivian Attribute Data Base.

Currently, there are seven hierarchical levels implemented in the Bolivian Attribute Data Base.

1. Attribute Data Base Record
2. Level Record
3. Quadrant Record
4. Element Record
5. 1st Sub-Element Record
6. 2nd Sub-Element Record
7. 3rd Sub-Element Record

F. MANAGEMENT SUBSYSTEM

The Management Subsystem of a digital GIS performs all the data handling operations which include, among others, the generation, interrogation and updating of data files.[9] According to Thierauf,[11] the purpose of a data management subsystem is "to store, organize, and retrieve the required data to produce meaningful information."

In the particular case of the Bolivian GIS, one of the primary functions of its data management subsystem is to

Data	+	Processing	=	Information
- Data Base Subsystems		- Management Subsystems - Modeling Subsystems - Output Subsystems		- Output Subsystems

The Input Subsystem is used to create the data base of the system.

In the particular case of the Bolivian digital GIS, the Data Base Subsystem is composed of two different but interrelated data bases, i.e., the Image Plane Data Base and the Attribute Data Base.

The Image Plane Data Base is composed

carry out data handling operations between the Image Plane Data Base and the Attribute Data Base.

G. MODELING AN ANALYSIS SUBSYSTEM

This part of a digital GIS deals with the operations of extracting the data from storage (data base subsystem) and performing the analytical operations needed to meet the requirements of the

problem at hand, for example, measurements of areas or calculation of distances, comparison of multiple data sets (between different data base elements), Boolean algebra operations (such as unions and intersections) up to extremely complex and sophisticated mathematical models that can be used for simulation and forecasting purposes.

H. OUTPUT SUBSYSTEM

Phillips[10] stated that "the purpose of the output subsystem is actually twofold: it must produce both the products required by the system user and some intermediate products required by the data analyst. Typical outputs required by the system user include maps, tables, photographs, and digital magnetic tapes. The data analyst often needs the same products, but usually in a much less permanent form." Phillips also emphasizes that "careful attention should be given to the specification of the output products, for the system's effectiveness will be judged primarily on the ability of these products to provide the desired information in a useful format."

III. DIGITAL GEOGRAPHIC INFORMATION SYSTEM FOR THE ORURO DEPARTMENT, BOLIVIA

Even though the system was conceptualized and designed for the entire Bolivian territory, the implementation of the system has been carried out for the Oruro Department, Bolivia (54,000 square kilometers).

Because of a severe restriction on the availability of basic natural resources data at greater levels of detail, the implementation of the system was performed at the Departmental (regional) level of detail, which consists of 500 meter x 500 meter cells. In order to fit the entire Oruro Department in one quadrangle, an additional quadrangle was designed (see Figures 3 and 10).

The digitization of the various elements contained in the data base was carried out following the procedures outlined above. The basic source materials were natural resources maps at a scale of 1:250,000 provided by the Bolivian ERTS/GEOBOL Program.

The Oruro Data Base Subsystem contains 14 elements in its Image Plane Data Base (see Figure 8), code-related to the Attributed Data Base. The coding of the different classes (thematic) units,

with a maximum of 256 (2⁸) classes was done taking into consideration the hierarchical nature of the system and trying in as much as possible to relate it to a national hierarchical classification scheme developed for that purpose for most of the elements present in the data base. Figure 11 shows part of the information stored in the Attribute Data Base for the Land Use/Land Cover element.

The first 4 elements are the 4 Landsat MSS mosaics, i.e., mosaics of bands 4, 5, 6 and 7 which provide the planimetric base for the geo-coded image plane. The mosaicking of 7 Landsat frames covering the Oruro Department was performed by the Jet Propulsion Laboratory (JPL). The Landsat imagery was resampled to 50 meter x 50 meter pixels and map projected to the Albers equal area projection. The final mosaic was segmented into 100 kilometer x 100 kilometer quadrangles of 2000 lines x 2000 samples (columns) each. The planimetric accuracy assessment performed at LARS showed an RMS error of 237 meters for the mosaic and 80 meters for the training control points (points used in the creation of the Landsat mosaic).

Since the system was implemented at the third level of detail (500 meter x 500 meter cells) it was necessary to aggregate the 50 meter x 50 meter spatial resolution of the mosaic into 500 meter x 500 meter pixels. After an in-depth investigation of four different algorithms developed to perform the aggregation, the averaged-pixels algorithm was selected.

The four algorithms used in the test were:

1. Image Shrink (IMSHK)
2. Image Average (IMAVG)
3. Image Square (IMSQR)
4. Image Deviation (IMDEV)

The Image Shrink (IMSHK) algorithm selects the center pixel of a specified 500 meter x 500 meter data window (10 x 10 pixel block) and produces an image in which the selected center pixel represents a 500 meter x 500 meter aggregated pixel.

The Image Average (IMAVG) algorithm calculates the average spectral response value of a 10 x 10 high resolution pixel block and creates a new image in which the resulting averaged pixel represents a 500 meter x 500 meter cell.

The Image Square (IMSQR) algorithm computes a new pixel value using the following formula:

$$\text{New Pixel Value} = \sqrt{\frac{\sum\limits_{i=1}^{\eta} x_i^2}{\eta}}$$

where

x_i = 50 meter x 50 meter pixel value within the specified window (10 x 10 pixel block).

η = 100 (total number of pixels within the window).

The Image Deviation (IMDEV) algorithm calculates the standard deviation of the 10 x 10 pixel block and then creates a new image in which the new pixel values represent 500 meter x 500 meter cells.

The averaged-pixels criterion used for degrading the spatial resolution of the digital Landsat mosaic is only applicable to the spectral elements of the Bolivian GIS image-plane data base. For the other elements of the Bolivian GIS image-plane data base, different aggregation criteria should be developed and tested. For example, for the soils and the land use elements neither of the four aggregation procedures described above would be applicable, instead a "voting" or "majority rule" criterion would be preferable.

Being aware of the impact of digitization cell size on inventory and mapping errors in a cellular Geographic Information System, a study following the investigations of Wehde[12] on this type of errors was also performed. Figure 12 illustrates the relationship between percent mapping errors and digitization cell size.

Working with the cell sizes for the different scales used for the Bolivian GIS and the graph from Figure 12, errors for each major map scale were determined and are listed in Table 2. This table shows that the locational error (mapping error) is 1.5% and the aereal extent error is 0.1% for all major map scales except for the 1:25,000 and the 1:250,000 scale maps, whose errors are 6.8% and 0.4%, respectively.

The Bolivian GIS will be primarily used for information concerning aereal extent. For the purposes of the Bolivian GIS the selected cell sizes are all within 0.5% predicted error in aereal extent.

Some algorithms were also developed for the analysis or modeling subsystem. These include calculations of aereal surface of each class in a specific element, aereal extent of one class from one element contained in a class from another element and also the capability of editing or updating the information stored in the Image Plane Data Base. Figure 13 shows an example of the editing capability of a portion of a soils map.

Computer programs were developed for the conversion of topographic maps into Digital Terrain Models (DTM). The digitization of terrain information (topographic maps) is somewhat different from the process of digitizing resource maps, such as land use or soils maps, in that the former requires interpolation of elevation values and estimation of slope and aspect, while the rasterization of other elements requires only filling in (painting) and labeling the areas within the polygons that delineate the different classes of the resource map. In order to accomplish the interpolation of elevation and calculation of the slope and aspect for every pixel in the digital geo-coded image plane a mathematical model (algorithm) was developed.

Figure 14 shows one kind of output product obtained from the Bolivian GIS Output Subsystem. It shows the Political Boundary element displaying in different gray levels the 111 cantons that form the Oruro Department. The output subsystem also has the capability of displaying the horizontal and vertical scales of the map and the attribute information related to the element being developed.

IV. CONCLUSIONS

Essentially this project consisted of the conceptualization and design of a digital Geographic Information System (GIS) for the entire territory of the Republic of Bolivia, and the development and implementation of this system for the Oruro Department.

A simplified schematic configuration of the Bolivian GIS is illustrated in Figure 5, and the natural resources, enviromental and socio-economic elements of the geo-coded image plane data base are shown in Figure 8. Detailed documentation about the Bolivian digital GIS is available in a series of quarterly progress reports.[13,14,15,16,17,18,19,20]

The most significant achievements derived from this project include:

- The design of a digital Geographic Information System of national scope.

- A thorough investigation and subsequent development of an algorithm that defines the optimum resource map projection for Bolivia, i.e., the Albers conical equal-area projection.

- Development of hierarchical classification schemes (legends) for the various thematic elements of the Bolivian GIS (classification coding).

- Development and Implementation of an addressing scheme for storing geo-referenced data in a digital image format.

- Development of a method for storing large quantities of data for natural resources inventories that allows managers, planners and decision makers to obtain useful information in an interactive mode at national, region (Departmental) and local levels.

- The design of this system provides the capability to store, manage, analyze and update effectively the country's natural resources, environmental and socio-economic data.

- The design of digitizing software for implementation on a microprocessor (APPLE II plus microprocessor).

- Creation of a digital Landsat MSS mosaic for the Oruro Department complete with a quantitative planimetric accuracy assessment.

- Development of computer programs for the conversion of topographic maps into Digital Terrain Models (DTM).

- Definition of procedures to determine quantitatively the mapping and tabulation errors resulting from digitization of resource maps.

- Determination of an appropriate "cell-aggregation" method for the Landsat MSS mosaic data.

The principal investigators of this project believe that the most important achievement derived from this cooperative effort between the Bolivian ERTS/GEOBOL Program and Purdue/LARS has been the effective transfer of the technology through the training of Bolivian technical personnel.

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AUTHOR BIOGRAPHICAL DATA

Luis A. Bartolucci, B.S., M.S., and Ph.D. in Geophysics from Purdue University, has been involved in Remote Sensing Research since 1969. He has played an active role in the development of remote sensing technology for applications in the area of water resources and has also made outstanding contributions in the field of thermal infrared radiation for remote sensing applications. In addition, Dr. Bartolucci has served as consultant to the U.S. Information Agency, the U.S. Agency for International Development, the Inter-American Development Bank and to several Latin American development agencies. He has been Principal Investigator and Project Director of several domestic and international research and training programs involving computer-aided processing and analysis of remotely sensed data for earth resources inventories.

Terry L. Phillips, B.S., M.S., Electrical Engineering, Purdue University, has held positions at Purdue University in the Electrical Engineering Department, National Cash Register Company, and the U.S. Navy. He has been a consultant to the Computer Science Corporation, U.S. Geological Survey, Iowa Geological Survey, the Colorado Intergovernmental ADP Council, U.S. AID, and other groups interested in remote sensing systems. He is engaged in the development of data handling and processing systems. He has been active in the applications of these systems for remote sensing since 1966. In 1976 he was recognized by NASA for the creative development of technology. He is a Senior Member of the Institute of Electrical and Electronics Engineers and a member of the Association for Computing Machinery, Data Processing Management Association, Tau Beta Pi, and Eta Kappa Nu societies.

Carlos R. Valenzuela holds a B.S. from the Agricultural State College, Deventer, The Netherlands, a M.S. from the International Institute for Aerial Surveys

and Earth Sciences (ITC), Enschede, The Netherlands and he is a Ph.D. candidate at Purdue University. He has been Soils Investigator for the ERTS/GEOBOL Bolivian Remote Sensing Program from 1977 to 1980, in charge of developing soil survey methodologies using Landsat MSS data. Mr. Valenzuela has participated, as a Visiting Scientist at the Laboratory for Applications of Remote Sensing (LARS), in the development of a Geographic Information System for Bolivia. He has also taught a Remote Sensing course at Ball State University at graduate and undergraduate levels. Currently, he is a Research Instructor at the Laboratory for Applications of Remote Sensing at Purdue University.
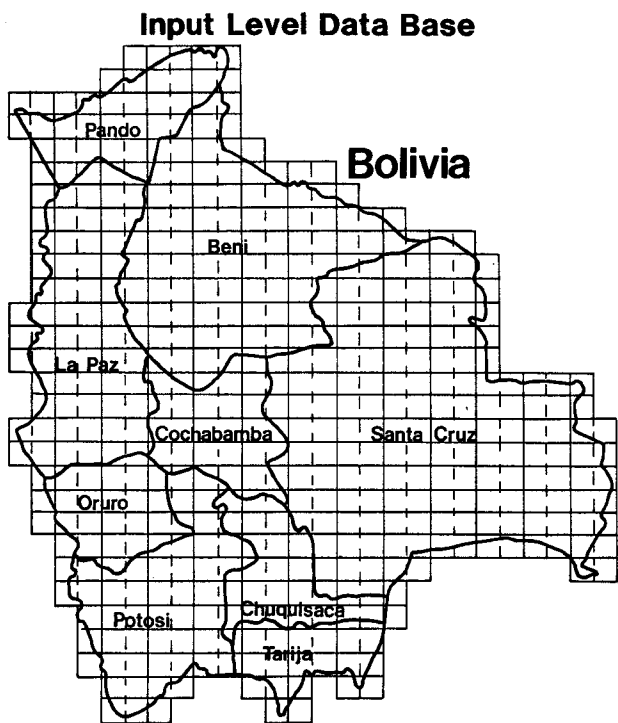
Input Level Data Base

Figure 1.   Level 1 Data Base Showing 492 Quadrants.   Each quadrant covers a 50 x 50 kilometer area.

Local Planning Level Data Base
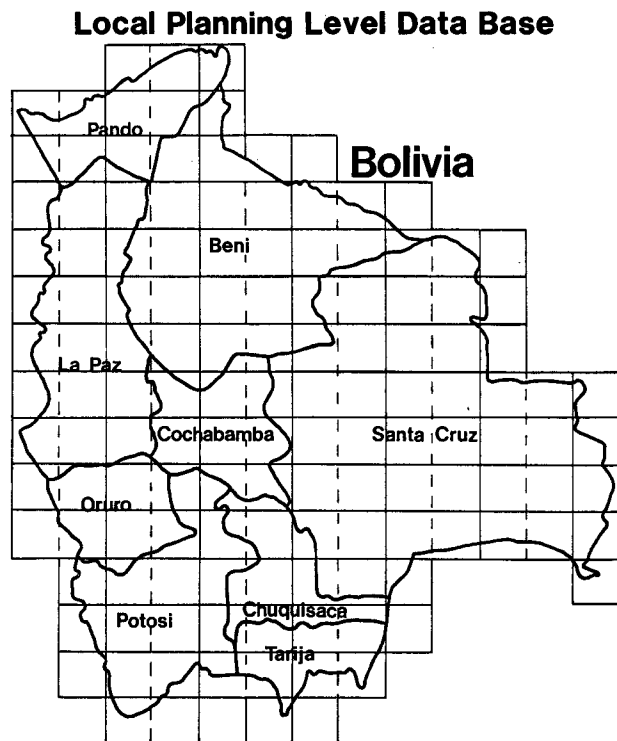
Figure 2.   Level 2 Data Base Showing 137 Quadrants.   Each quadrant covers a 100 x 100 kilometer area.

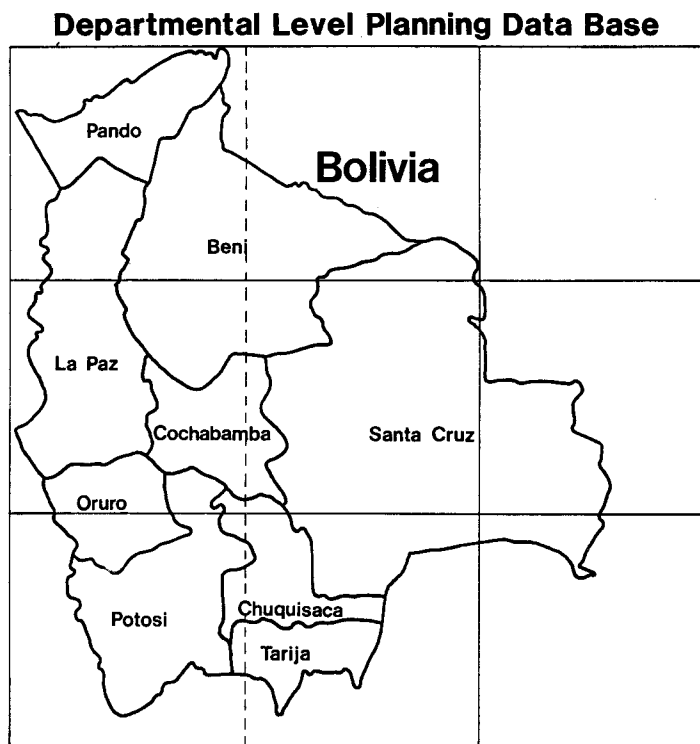**Departmental Level Planning Data Base**

Figure 3.   Level 3 Data Base Showing 9 Quadrants.
Each quadrant covers a 500 x 500 kilometer area.

National Planning Level Data Base

Figure 4. Level 4 Data Base Showing a 1300 x 1500 Kilometer Area.

1 area number
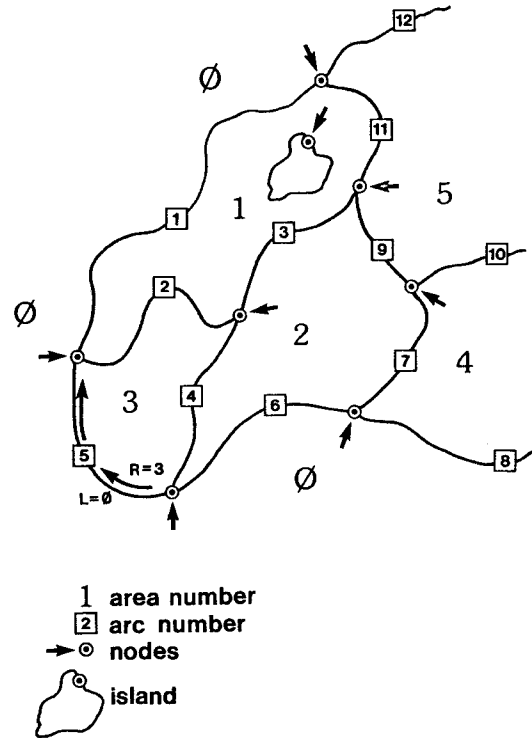2 arc number
➤⊙ nodes
island

Figure 6. Basic Elements of a Resource Polygonal Map.

Digital Geographic Information System Components
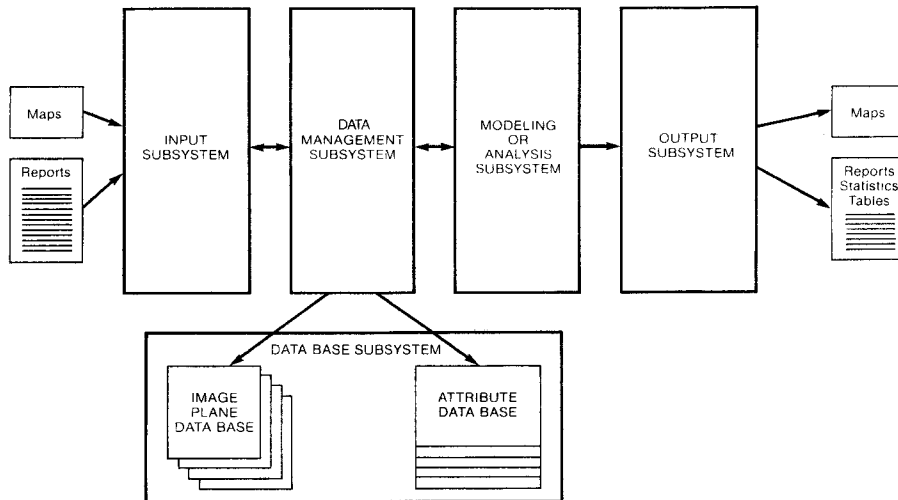
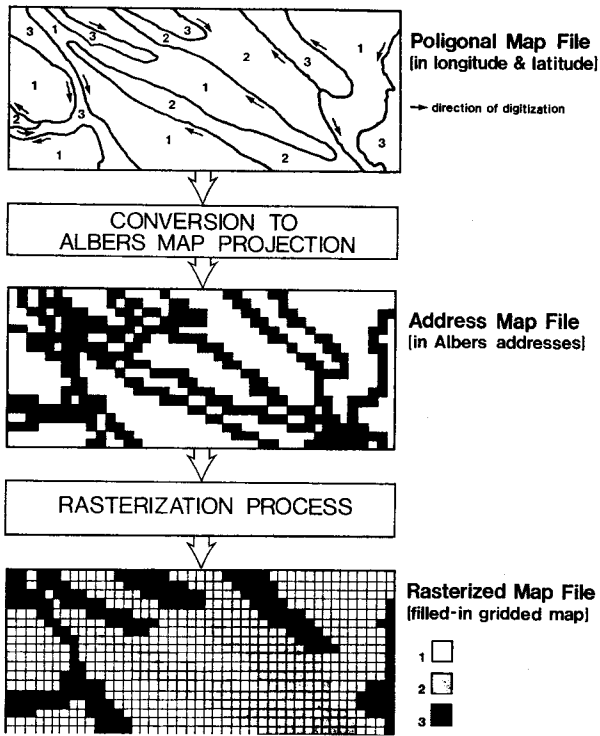Figure 5. Basic Components of a Digital Geographic Information System.

Poligonal Map File
(in longitude & latitude)

→ direction of digitization

CONVERSION TO ALBERS MAP PROJECTION

Address Map File
(in Albers addresses)

RASTERIZATION PROCESS

Rasterized Map File
(filled-in gridded map)

1 ☐
2 ☐
3 ■

Figure 7. Steps Involved in the Conversion of a Polygonal Map File to a Rasterized (Cellular or Gridded) Map File.

ATTRIBUTE RECORD

LEVEL RECORD
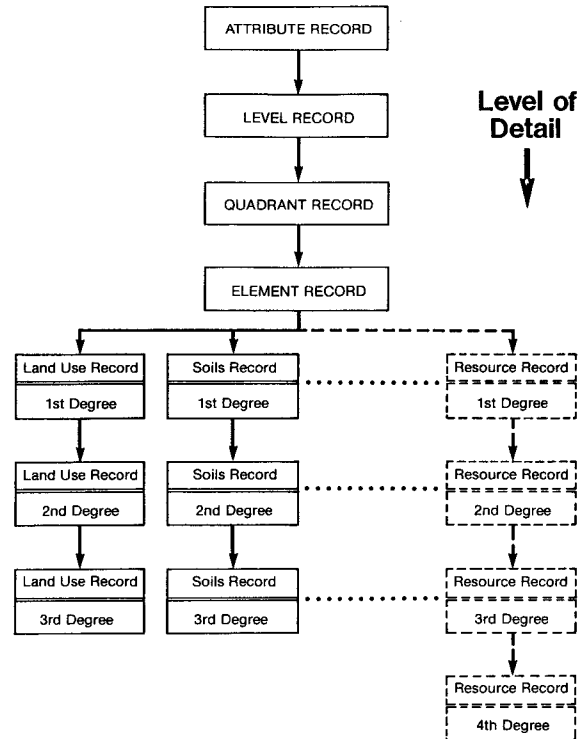
QUADRANT RECORD

ELEMENT RECORD

Level of Detail

↓

| Land Use Record | Soils Record | ·········· | Resource Record |
| 1st Degree | 1st Degree | | 1st Degree |

| Land Use Record | Soils Record | ·········· | Resource Record |
| 2nd Degree | 2nd Degree | | 2nd Degree |

| Land Use Record | Soils Record | ·········· | Resource Record |
| 3rd Degree | 3rd Degree | | 3rd Degree |

| Resource Record |
| 4th Degree |

Figure 9. Hierarchical Structure of the Bolivian Attribute Data Base.

Aspect (Azimuth)
Slope
Elevation
Geomorphology
Geology
Hydrology
Meteorology
Soils
Land Cover/Land Use
Political Boundaries*
Landsat Mosaic (Band 7)
Landsat Mosaic (Band 6)
Landsat Mosaic (Band 5)
Landsat Mosaic (Band 4)

Image Plane Data Base

*the Political Boundaries element include the departmental, provincial, and countour boundaries of Oruro, Bolivia It also contains the Socio-Economic variables.
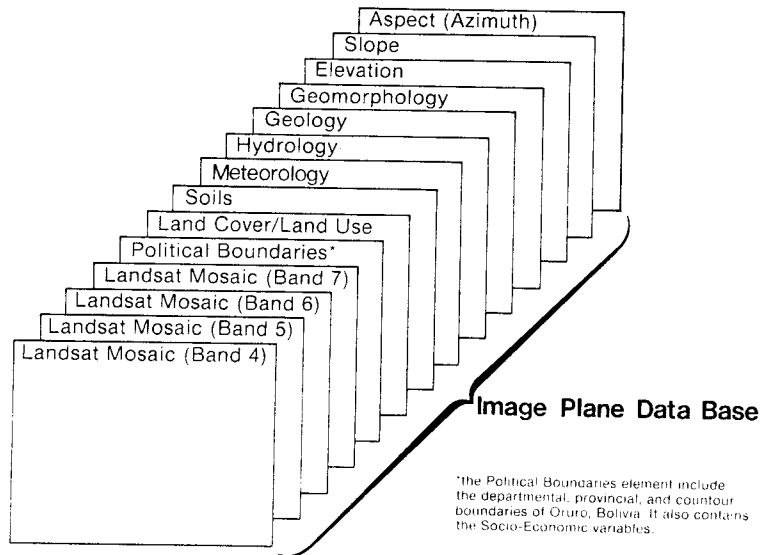
Figure 8. Image Plane Data Base for the Oruro Department GIS.

Albers Projection Addresses

Albers Address
x = 1
y = 1

x = 2001
y = 16001

x = 10001
y = 16001

x = 6001
y = 20001

x = 2001
y = 24001

X = 10001
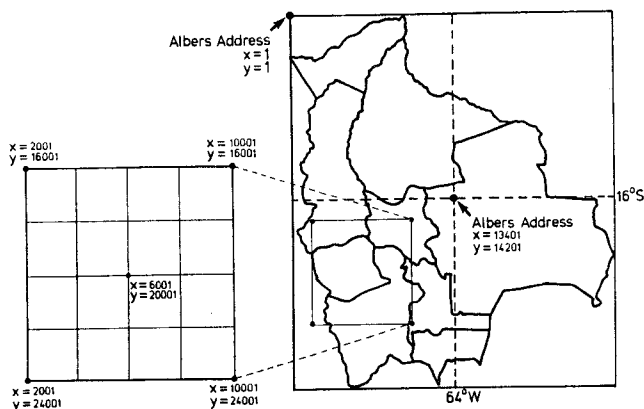y = 24001

Albers Address
x = 13401
y = 14201

16°S

64°W

Figure 10. The Albers Projection Addresses
for the Quadrangle Created for the Oruro Department.

NATURAL RESOURCE DATABASE
FILL CHARACTER INFORMATION OUTPUT

DATE PREPARED   7/21/81

LEVEL CODE   300   LEVEL NAME   REGIONAL

QUADRANT CODE   10 QUADRANT NAME ORURO

ELEMENT CODE

FIRST LEVEL CODE   1   NAME RANGE AND/OR SHRUBLANGE   FILL ( )

SECOND LEVEL CODE   1   NAME HIGHLAND RANGE AND/OR SHRUBLAND   FILL ( )

THIRD LEVEL CODE   1   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN WET ENVIRONMENT   FILL (1)

THIRD LEVEL CODE   2   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN TEMPORARY WET ENVIRONMENT   FILL (2)

THIRD LEVEL CODE   2   SUBDOMINATE CODE   114
NAME RANGE/SHRUBLAND IN TMRY WET ENVIRON AND RANGE/SHRUB IN SALINLAND FILL (3)

THIRD LEVEL CODE   2   SUBDOMINATE CODE   612
NAME RANGE/SHRUBLAND IN TEMPORARY WET ENVIRONMENT AND SALINE LANDS   FILL (4)

THIRD LEVEL CODE   2   SUBDOMINATE CODE   613
NAME RANGE/SHRUBLAND IN TEMPORARY WET ENVIRONMENT AND SANDY AREAS   FILL (5)

THIRD LEVEL CODE   3   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN DRY ENVIRONMENT   FILL (6)

THIRD LEVEL CODE   3   SUBDOMINATE CODE   114
NAME RANGE/SHRUBLAND IN DRY ENVIRONMENT AND RANGE/SHRUB IN SALINELAND FILL (7)

THIRD LEVEL CODE   3   SUBDOMINATE CODE   613
NAME RANGE/SHRUBLAND IN DRY ENVIRONMENT AND SANDY AREAS   FILL (8)

THIRD LEVEL CODE   3   SUBDOMINATE CODE   614
NAME RANGE/SHRUBLAND IN DRY ENVIRONMENT AND ROCK OUTCROPS   FILL (9)

THIRD LEVEL CODE   4   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN SALINE LANDS   FILL (10)

THIRD LEVEL CODE   4   SUBDOMINATE CODE   113
NAME RANGE/SHRUBLAND IN SALINE LAND AND RANGE/SHRUB IN DRY ENVIRONMENFILL (11)

THIRD LEVEL CODE   4   SUBDOMINATE CODE   613
NAME RANGE/SHRUBLAND IN SALINE LAND AND SANDY AREAS   FILL (12)

SECOND LEVEL CODE   2   NAME INTER ALTITUDE RANGE/SHRUBLANDS   FILL ( )

THIRD LEVEL CODE   1   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN DRY ENVIRONMENT   FILL ( )

THIRD LEVEL CODE   2   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN TEMPORARY WET ENVIRONMENT   FILL ( )

THIRD LEVEL CODE   3   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN DRY ENVIRONMENT   FILL ( )

THIRD LEVEL CODE   4   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN SALINE LANDS   FILL ( )

SECOND LEVEL CODE   3   NAME LOWLAND RANGE AND/OR SHRUBLANDS   FILL ( )

THIRD LEVEL CODE   1   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN WET ENVIRONMENT   FILL ( )

THIRD LEVEL CODE   2   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN TEMPORARY WET ENVIRONMENT   FILL ( )

THIRD LEVEL CODE   3   SUBDOMINATE CODE   0
NAME RANGE AND/OR SHRUBLAND IN DRY ENVIRONMENT   FILL ( )

Figure 11. Example of Information Stored
in the Attribute Data Base for the Land Use/
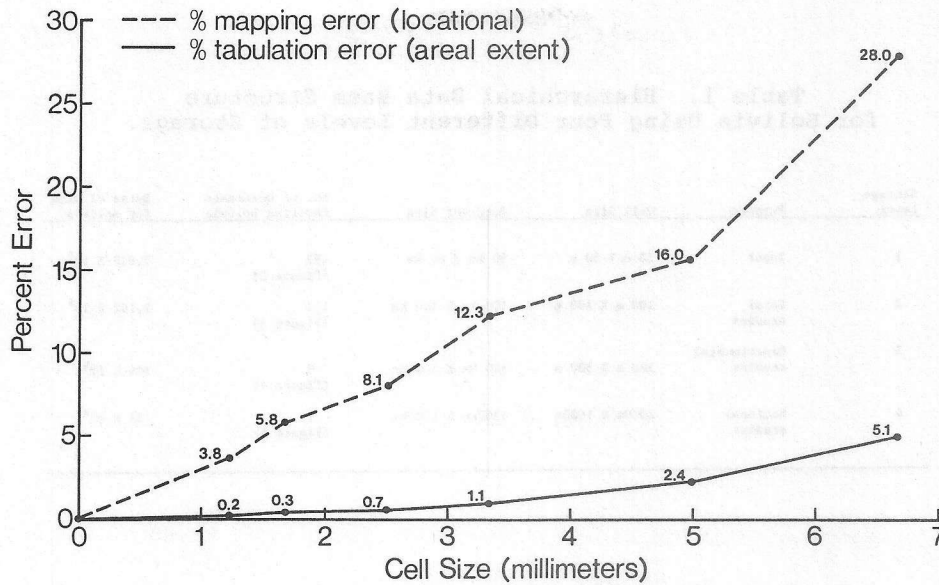Land Cover Element.

Figure 12. Relationship Between Mapping Errors
(in %) and Digitization Cell Size (modified from Wedhe).

Figure 13. This Figure Shows an
Alphanumeric Representation of a Portion
of a Soils Map of the Oruro Department,
Stored in the Image Data Plane. Note in
the top figure the two blank areas indi-
cated by the arrows, which have several
pixels. The bottom figure shows the same
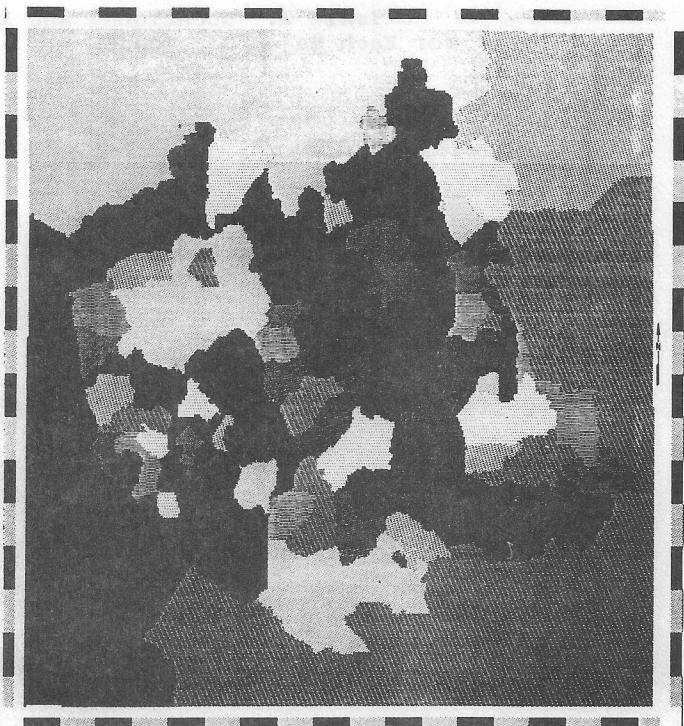portion of the map after editing the data.

Figure 14. Gray-scale Map of the Oruro
Department Showing the 111 Different Cantones.

Table 1. Hierarchical Data Base Structure
for Bolivia Using Four Different Levels of Storage.

Storage Level	Purpose	Cell Size	Quadrant Size	No. of Quadrants Covering Bolivia	Bytes of Data for Bolivia
1	Input	50 m X 50 m	50 km X 50 km	492 (Figure 2)	7,872 X 10^6
2	Local studies	100 m X 100 m	100 km X 100 km	137 (Figure 3)	2,192 X 10^6
3	Departmental studies	500 m X 500 m	500 km X 500 km	9 (Figure 4)	144 X 10^6
4	National studies	1000m X 1000m	1300km X 1500km	1 (Figure 5)	31 X 10^6

Table 2. Locational and Aerial Extent Errors
for Each Major Map Scale.

	Cell Size		Error(%)	
Scale	Ground(m)	Map(mm)	Locational	Areal Extent
1:25,000	50	2	6.8	0.4
1:50,000	50	1	1.5	0.1
1:100,000	100	1	1.5	0.1
1:250,000	500	2	6.8	0.4
1:500,000	500	1	1.5	0.1
1:1,000,000	1000	1	1.5	0.1