THEMATIC MAPPING, LAND USE, GEOLOGICAL STRUCTURE AND WATER RESOURCES IN CENTRAL SPAIN

Project no. 28760

FINAL REPORT

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AGENCY: Instituto Geográfico y Catastral
General Ibañez de Ibero, 3 - MADRID - 3 (Spain)
6 November, 1976

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CONTRIBUTING ORGANIZATIONS

- Centro de Estudios Hidrográficos del Ministerio de Obras Públicas.
- Instituto de Geografía Aplicada del Consejo Superior de Investigaciones Científicas.
- Instituto de Edafología del Consejo Superior de Investigaciones Científicas.
- Servicio de Fotogrametría y Fotointerpretación de la Universidad Politécnica de Madrid.
- Cátedra de Geodinámica Interna de la Universidad Complutense de Madrid.
- Cátedra de Geografía de la Universidad Complutense de Madrid.
- Centro de Investigación UAM-IBM de la Universidad Autónoma de Madrid.
- Laboratorio de Teledetección del Instituto Geográfico y Catastral.
# INDEX

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>OBJECTIVES</td>
<td>4</td>
</tr>
<tr>
<td>PARTICIPANT ORGANIZATIONS</td>
<td>6</td>
</tr>
<tr>
<td>TECHNIQUES</td>
<td>11</td>
</tr>
<tr>
<td>DATA QUALITY</td>
<td>14</td>
</tr>
<tr>
<td>DATA DELIVERY</td>
<td>14</td>
</tr>
<tr>
<td>PUBLICATIONS</td>
<td>17</td>
</tr>
<tr>
<td>FELLOWSHIP</td>
<td>17</td>
</tr>
<tr>
<td><strong>CARTOGRAPHY</strong></td>
<td></td>
</tr>
<tr>
<td>EVALUATION OF LANDSAT MSS DATA FOR UPDATING CARTOGRAPHY AT SMALL SCALES IN CENTRAL SPAIN</td>
<td>20</td>
</tr>
<tr>
<td><strong>DIGITAL PROCESSING</strong></td>
<td></td>
</tr>
<tr>
<td>STUDY OF RADIOMETRIC ENHANCEMENT METHODS APPLIED TO LANDSAT MSS IMAGES</td>
<td>70</td>
</tr>
<tr>
<td>DETERMINATION OF UNCORRELATED BANDS IN A LANDSAT MSS IMAGE</td>
<td>93</td>
</tr>
<tr>
<td>THE BAND RATIOING TECHNIQUES APPLIED TO LANDSAT MSS IMAGES</td>
<td>109</td>
</tr>
<tr>
<td><strong>EDAPHOLOGY</strong></td>
<td></td>
</tr>
<tr>
<td>MADRID AND ITS ENVIRONMENT: LAND USE AND SOILS BY DIGITAL ANALYSIS OF LANDSAT DATA</td>
<td>128</td>
</tr>
<tr>
<td><strong>FORESTRY</strong></td>
<td></td>
</tr>
<tr>
<td>DIFFERENTIATION OF CONIFERS SPECIES IN CENTRAL SPAIN BY DIGITAL ANALYSIS OF LANDSAT DATA</td>
<td>155</td>
</tr>
</tbody>
</table>
GEOLOGY
DETERMINATION BY MEANS OF LANDSAT IMAGES OF DIFFERENT GEOLOGICAL STRUCTURES IN THE CENTRAL AREAS OF IBERIAN PLATEAU .......................... 172

GEOMORPHOLOGY
SOME GEOMORPHOLOGICAL ASPECTS OF LANDSAT-2 IMAGES OVER CENTRAL WESTERN SPAIN .................. 209

LAND USE
APPLICATION OF LANDSAT-2 DATA TO LAND USE MAPPING IN CENTRAL SPAIN ................................. 216

REMOTE SENSING TECHNIQUES
REMOTE SENSING TECHNIQUES IN A MULTISPECTRAL SURVEY OF ARANJUEZ TEST SITE ..................... 223

WATER RESOURCES
APPLICATION OF LANDSAT-2 DATA TO HYDROLOGY IN CENTRAL SPAIN ............................................. 259
THEMATIC MAPPING, LAND USE, GEOLOGICAL STRUCTURE AND WATER RESOURCES IN CENTRAL SPAIN.

Project no.28760

I. INTRODUCTION

This Final Report is submitted to NASA as result of one year of investigations carried out in multidisciplinary mode by the participant organizations in project no.28760, for the purpose of studying applications of LANDSAT -2 data to several scientific fields in Central Spain.

This project involved the participation of various official agencies and working groups related to the problem of surveying the earth surface for their own scientific application. Instituto Geográfico y Catastral is the agency that holds the coordinative function in project no.28760, with the contribution of the following organizations:

- Center of Hydrographic Studies, of the Ministry of Public Works
- Institute of Applied Geography, of the Head Council of Scientific Research
- Institute of Edaphology, of the Head Council of Scientific Research
- Service of Photogrammetry and Photointerpretation, of the Polytechnic University of Madrid
- Department of Internal Geodynamics, of the Complutense University of Madrid
- Department of Geography, of the Complutense University of Madrid
In spite of political changes occurred in the country during the last year, the basic team of research has been maintained as participant in the project, although some working groups had to resign their contribution, mainly because variations arose in their scientific and technical staff able to conduct it. On the other hand, several new organizations have joined the multidisciplinary group which, as result of its reinforced capability for analysing LANDSAT-2 data, was ready to envisage new applications of the satellite multispectral information, although such new scientific works had not been considered in the proposal submitted to NASA for approval of this project in January 1973.

The items of investigation studied have been the following:
- cartography
- digital processing
- edaphology
- forestry
- geology
- geomorphology
- land use
- remote sensing techniques
- water resources

As general objective was defined the research in various disciplines by means of LANDSAT-2 data taken over Central Spain, for the purpose of developing an operational methodology able to contemplate future space programs as a valuable working tool in the knowledge of the earth disciplines. Every working group has conducted the investigation applied to his own area
Area of study in Central Spain selected in project no. 28760
of interest, but all the participating organizations have the benefit of an exchange of know-how and a continuous contact between their scientific personnel. Furthermore, the techniques and equipment available have been exploited in common, in a joint effort to carry out this NASA supported project for the benefit of all the national community.

As principal result of this project can be stated that a group of investigators has worked together during one year, attending various results in the applications of LANDSAT information to their own area of scientific interest. In this case, LANDSAT-2 satellite has been the agglutinant which made possible the success of the multidisciplinary group formed.

In the adjoining figure is represented the area of Central Spain which was selected to carry out this project.

2. OBJECTIVES

Because the heterogeneous nature of the multidisciplinary group in charge of this project, various specific objectives have been defined in each application. They are the following:

**Cartography.** As a first step it was intended to determine whether or not LANDSAT MSS data could be used for updating maps at small scale in Central Spain, with enough cartographic accuracy. Once established such capability, the purpose of the investigation was focused in defining what kind of data could be extracted (or updated) from LANDSAT information. As a third step it was determined the application of the above mentioned possibilities to the specific case of small scale Maps in the country, producing an updated at scale 1:200,000 of the Central Region.
Digital processing. In this field it was intended to study radiometric enhancement methods when applied to LANDSAT MSS data, for the purpose of obtaining improved images through a DICOMED D-47 film recorder. Research was focused to the analysis of NASA CCTs when converted to tapes in 8-bit at linear mode.

As a second objective it was defined the need of obtaining uncorrelated bands of the MSS sensor, in order to exclude redundant information used as input to an automatic classifier. Such objective was accomplished by study of linear combinations of channels in an image with an arbitrary number of them.

As a third objective it was intended to obtain relevant information from MSS data by the use of band ratioing techniques. Such procedure has been applied to eliminate light cloud cover and in geological studies.

Edaphology. This item has been studied with digital MSS data for the purpose of selecting, by clustering techniques spectral classes which could be representative in Central Spain of certain types of land use and soils, allowing their automatic classification in computer.

Forestry. The application of LANDSAT data to forestry had the purpose of differentiating several types of conifers species in Central Spain by means of a supervised classification in computer. Species selected have been the most common in the area: Pinus pinaster Sol., Pinus pinea L., and Pinus sylvestris L.

Geology. Two main objectives were defined in this scientific field. First, it was evaluated the capability of LANDSAT images to detect ample geological structures in Central Spain by photointerpretation techniques. Secondly, an analysis of band ratios of MSS digital data was done with the purpose of defining the best combinations to be applied in geology.
Geomorphology. In this field some analysis was conducted for evaluating the geomorphological characteristics of LANDSAT images when studied by photointerpretation techniques, reviewing their capability for stereoscopic vision and various morphostructural aspects.

Land use. It was intended to do thematic cartography of land use by photointerpretation of LANDSAT images to small scales. As result of this work two maps have been produced at scales 1:250,000 and 1:500,000 of the Province of Madrid.

Remote Sensing techniques. A multispectral survey was conducted in Aranjuez test site with the purpose of applying aerospace remote sensing techniques to various disciplines in a multidisciplinary approach. LANDSAT information was used in the intent of correlating it to the data obtained by means of airborne photographic cameras and a multispectral scanner Daedalus.

Water resources. In this work an evaluation of LANDSAT data has been carried out in multidisciplinary mode for determining their real applications in hydrology. The area of study as test site has been the Guadarrama basin. Agronomic, forestry, hydrological and geological photointerpretation of the area was conducted, as well as digital processing of LANDSAT data.

3. PARTICIPANT ORGANIZATIONS

Since the date of submission of proposal for this project, in January 1973, several participant organizations have left behind their contribution. They are the following:

- Instituto Geológico y Minero de España
- Comisión de Planeamiento y Coordinación del Area Metropolitana de Madrid (COPLACO).
As stated before, such situation was forced by political changes occurred in the country during the last year, and because these working groups did not maintain their original staff of scientists and technicians able to conduct the project. The new participants who joined the multidisciplinary group in the last four years are the following:

- Centro de Investigación UAM-IBM de la Universidad Autónoma de Madrid.
- Servicio de Fotogrametría y Fotointerpretación de la Universidad Politécnica de Madrid.

The IBM-Scientific Center provided in this project all the required digital processing of LANDSAT data, carrying out a multidisciplinary work in connection with all the participants. During the year 1974 an IBM 360/65 computer (1024 K) was installed in the Center, interfaced to an interactive TV terminal RAMTEK. The software used was ERMAN-II program, which is the commercial version of ERIPS program developed by IBM-PSD for NASA in Houston. The capabilities of ERMAN-II program are the following:

- Pattern Recognition
- Image Registration
- Load
- Image composition
- Image manipulation and display
- Delog

Acting of the IBM-Scientific Center in the project was possible because its dedication to support research programs in the country contributing to the benefit of the national community.
### Table 1

<table>
<thead>
<tr>
<th>EQUIPMENTS</th>
<th>IGC REMOTE SENSING LABORATORY/PHOTOINTERPRETATION FACILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INPUT</td>
</tr>
<tr>
<td></td>
<td>PRODUCT</td>
</tr>
<tr>
<td>LIGHT TABLES</td>
<td>ROLL FILM</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

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<thead>
<tr>
<th>HARDWARE</th>
<th>IGC REMOTE SENSING LABORATORY/COMPUTER FACILITY</th>
</tr>
</thead>
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<tr>
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<td>PRODUCT</td>
</tr>
<tr>
<td>FILM RECORDER INTERFACE TO PDP 11/45 COMPUTER</td>
<td>LANDSAT</td>
</tr>
<tr>
<td></td>
<td>CCT REFORMATED</td>
</tr>
<tr>
<td></td>
<td>AERIAL MSS REFORMATED</td>
</tr>
<tr>
<td>IBM 360/65 &amp; IBM 370/145 REMOTE TERMINAL</td>
<td>DIGITAL TAPES</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Table 3.

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>ENVIRONMENTAL MEASUREMENT</th>
<th>PARAMETER</th>
<th>RANGE</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
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<td>WATER</td>
<td>TRANSPORTATION</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BOAT</td>
<td>LAND</td>
<td>TRANSPORTATION</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CONTACT</td>
<td>WATER/AIR</td>
<td>SURFACE TEMPERATURE</td>
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</tr>
<tr>
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<td>LAND</td>
<td>TEMPERATURE</td>
<td>30 cm DEPTH</td>
<td>-10° ± 65°</td>
</tr>
<tr>
<td>SOIL</td>
<td>WATER</td>
<td>TEMPERATURE UNTIL 1.5 m DEPTH</td>
<td>-10° ± 60°</td>
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<tr>
<td>THERMOMETER</td>
<td>WATER</td>
<td>ACIDITY</td>
<td>0 - 14</td>
<td>INDICATOR</td>
</tr>
<tr>
<td>pH-METER</td>
<td>LAND</td>
<td>WIND SPEED</td>
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<td>REGISTER</td>
</tr>
<tr>
<td></td>
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<td>WIND DIRECTION</td>
<td>0° - 360°</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RELATIVE HUMIDITY</td>
<td>0 - 100%</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>TEMPERATURE</td>
<td>-35° ± 49°C</td>
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</tr>
<tr>
<td>AUTOMATIC METERIAL STATION</td>
<td>AIR</td>
<td>COLOR TURBIDITY</td>
<td>VARIABLE</td>
<td>INDICATOR</td>
</tr>
<tr>
<td>SPECTROPHOTOMETER</td>
<td>WATER</td>
<td>SUSPENDED SOLIDS</td>
<td>57 TESTS ON LABORATORY</td>
<td></td>
</tr>
<tr>
<td>SPECTROMETER</td>
<td>LAND</td>
<td>PERCENT DIRECTIONAL REFLECTANCE</td>
<td>400 nm</td>
<td>COMPUTER PRINTOUT</td>
</tr>
<tr>
<td>CONDUCTIVITY METER</td>
<td>WATER</td>
<td>SALINITY CONDUCTIVITY</td>
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</tr>
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<td>INDICATOR</td>
</tr>
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<td>equipments</td>
<td>igc remote sensing laboratory/library facility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>products</td>
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<td></td>
</tr>
<tr>
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<td>NTIS MICROFICHES</td>
<td>4&quot; x 5&quot;</td>
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<td>MICROFILM READER</td>
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<td>16 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>BOOKS REVIEWS NEWSLETTERS</td>
<td>ANY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARCHIVE</td>
<td>IMAGES</td>
<td>ANY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUDIOVISUAL</td>
<td>FILMS</td>
<td>ANY</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.
As a non profit organization the Center is governed by a Board of Trustees under the presidency of the Autonomous University of Madrid rector.

The Service of Photogrammetry and Photointerpretation has conducted in this project basic field work during the multispectral survey of Aranjuez test site, mainly focused to the identification of different types of farming crops. The Service has photointerpretation facilities and conducts every year several courses on photogrammetry, photointerpretation and related applications.

4. TECHNIQUES

LANDSAT information was studied in this project in two different modes:

- photographic images: most of them in black and white paper prints at scale 1:500,000.
- digital tapes: which have been provided by NASA upon request to the EROS Data Center.

MSS information over Central Spain was multispectral and multitemporal, covering all the area with 25 images from October 1975 to April 1976.

In an effort to provide to all participants in the project with their needed LANDSAT imagery and digital processing capability, Instituto Geográfico y Catastral (I.G.C.) has installed during the year 1975 a Remote Sensing Laboratory which was intended also for developing other national programs on remote sensing. Although the Laboratory can conduct research in various scientific fields in multidisciplinary mode, its major participation in the project has been focused to the following activities:
- reproduction work of LANDSAT 70 mms transparencies (-) and enlargement to operational scales in photointerpretation.
- evaluation of the cartographic applications of LANDSAT imagery and production (or updating) of maps at small scale. This activity was carried out in connection with the Cartography Division of I.G.C.
- Support to the IBM-Scientific Center of the Autonomous University of Madrid for developing a digital processing capability of LANDSAT data, and conversion of tapes to images by means of a DICOMED D-47 film recorder.

The Remote Sensing Laboratory has carried out also the relations with NASA in this project, as well as the submission of Quarterly and Final Reports, upon receipt of them from the multidisciplinary group. Printing work was done by the Cartographic Division of I.G.C. In tables 1 to 5 is presented the structure and facilities of the Laboratory, as they were submitted in the First Quarterly Report.

As the project was multidisciplinary every participant has used the techniques required for his own scientific application, and such techniques have shown very different from one group to the other. Because they are indicated in the various contributions, none comment is included in this section on such subject.

Some remarks are exposed here on the photographic processing of LANDSAT data conducted by the Remote Sensing Laboratory of I.G.C. This activity has been divided in two part, each one requiring different techniques:

1. Black and white processing. The original 70 mms transparencies (-) have been used in two ways:
   a) contact reproduction to positive 70 mm transparency. This
product was required as input working document for the additive color composite viewer, which shows false color images enlarged at scale 1:500,000 on horizontal screen. The reproductions showed problems because the critical density requirements, in the gray level scale, of the viewer. Original negatives had to be reduced in their maximum density to 0.2 units lower. Reproduction was done on Agfa Gevarex GO 21P film. Values were also obtained, in the straight part of the relative logE curve, for each developing time. Densitometric analysis were made on a Densichron Welch equipment:

b) enlargement on paper print at scale 1:500,000. A total of 880 copies, including all four bands MSS, have been distributed to participants. Reproduction was done on Agfa Copyline Projection P150 WF paper, automatically processed on a PAKO film processor.

2. Color processing. This capability was developed as result of the need for reproducing and enlarging images obtained through the DICOMED D-47 film recorder. The film obtained from the recorder, in cut sheets 4"x 5", was not processed at the I.G.C., but this was done by commercial photographic laboratories in Madrid.

The types of color films used were the following:
- Kodak Ektachrome Daylight 6115 (+)
- Kodak Vericolor II 4107 (-).

Once the film processed, enlargement was conducted by the following techniques:
- Negative to positive on Kodak color paper RC37 and 2 step Besseler chemicals
- Positive to positive on Cibachrome color paper and P-18 chemicals.
Enlargements had a maximum size of 40x50 cms in both cases, being able to provide part of LANDSAT images at scale 1:200,000. Processing in color at such scale was done only with subscenes corresponding to the Province of Madrid for cartographic purposes, and no distribution was intended of the images to the contributing organizations.

5. DATA QUALITY

Images received from EROS Data Center were bulk photographic products and enlarged copies at scale 1:1,000,000. Enclosed is in table 6 the minimum and maximum value of densities in each original negative received, corresponding to all LANDSAT images taken over Central Spain in bands 4, 5, 6 and 7. As it can be seen from table 6, the extreme values of the gray level scale have strong variations, which made difficult the reproduction work and corresponding photointerpretation based on changes in tonalities. Measurement of densities has been done on a Macbeth densitometer by transparency.

6. DATA DELIVERY

Delivery of information was done following the flow-diagram enclosed, through the Air Attachee to the Spanish Embassy in Washington to the Comisión Nacional de Investigación del Espacio (CONIE). From that point LANDSAT information was forwarded to the Principal Investigator for reproduction and distribution to the participant organizations.

Although information received was satisfactory and none delay was observed in delivery, the first images supplied for this project have been sent in October 1975; which represented a
Table 6. Minimum and maximum densities of the original bulk negatives received from EROS Data Center, corresponding to LANDSAT-2 images taken over Central Spain.
DATA FLOW FROM NASA TO P.I.

- NASA/GSFC
- CONIE (Spain)
- PRINCIPAL INVESTIGATOR
  - IGC
- CO-INVESTIGATORS
- IGC COMPUTER CENTER
  - PROCESSING DIGITAL TAPE MSS
- IGC PHOTO PROCESSING
- IGC ARCHIVE

DATA FLOW FROM P.I. TO NASA

- CO-INVESTIGATORS
- PRINCIPAL INVESTIGATOR
  - IGC
- CONIE
- NASA/GSFC
- PERIODICAL FINAL REPORT AND MAPS
- PERIODICAL REPORT TECHNICAL INFORMATION EXCHANGE
- CONCERNED ORGANIZATIONS & AUTHORITIES
retard in the commencement of the investigation and a lengthening in the date of submission of this Final Report, after one year of active work with LANDSAT data over Central Spain.

7. PUBLICATIONS

A Remote Sensing Newsletter has been published since September 1975. It included continuous references to the development of this project, images received from NASA, remote sensing equipments available in Spain, publications, congress, etc. This Newsletter is being distributed free of charge to persons directly related to remote sensing technology or applications, both domestic and foreign. Other scientific publications are included in the bibliography presented by participants.

8. FELLOWSHIP

In the intent of training scientists and technicians in the new technology of remote sensing, several fellowship have been given by IBM-Scientific Center to participants in this project.

At the request of the Center, the Institute of International Education (IIE) has administered a fellowship training program which will continue in the following years. This program provides two six-month fellowship per year, at U.S. universities or institutions such as Purdue, EROS Data Center, U.S. Geological Survey and NASA facilities.

Completed fellowship

Grantee: José Luis Labrandero Sanz
Spanish Institution: Department of Soils, Institute of Edaphology, Head Council of Scientific Research.
Education and training program has been carried out at Purdue University during six months under the supervision of Professor M.F. Baumgardner

Grant: $11,500

Present fellowship

Grantee: Laura Muñoz
Spanish Institution: Department of Internal Geodynamics.
Complutense University of Madrid.

Education and training program is being carried out at:

End of this grant in March 1977.
Grant: $11,000

Future fellowship

The following candidates have been nominated
Ramón López Muñiz
Spanish Institution: Instituto Geográfico y Catastral

Antonio Carceller Loras
Spanish Institution: Instituto Geográfico y Catastral

Education and training Center: Jet Propulsion Laboratory/California Institute of Technology.
EVALUATION OF LANDSAT MSS DATA FOR UPDATING CARTOGRAPHY AT SMALL SCALES IN CENTRAL SPAIN.

Germán L. Lemos and Jesús Roca Novoa

Remote Sensing Laboratory
Geographic and Cadastral Institute
Madrid
SPAIN.
CARTOGRAPHY

EVALUATION OF LANDSAT MSS DATA FOR UPDATING CARTOGRAPHY AT SMALL SCALES IN CENTRAL SPAIN.

By Germán L. Lemos and Jesús Roca Novoa
Laboratorio de Teledetección
Instituto Geográfico y Catastral
Madrid.

1. INTRODUCTION

Although cartography was not defined as the main application of LANDSAT satellites, after the malfunction of the RBV cameras with their 81 reseau marks, cartographers turned the attention to the use of MSS data as a document for mapping. As cartographic requirements are subject to limits of tolerance more strict than the Earth science disciplines, the information supplied by LANDSAT has to be studied in a highly strict way for such application.

After the geometric correction of MSS data done by NASA, they have to be positioned by reference to a geodetic system for defining whether or not they can be used as a cartographic document.

As there is a need of information for updating maps at small scales, and such information is normally obtained by generalization of maps at larger scale, LANDSAT data are contemplated here as a valuable tool for updating existing cartography in central Spain. Once defined that MSS data are able to update items of interest in a map, the following questions come immediately: what items of interest can be updated? is LANDSAT able to define all of them?, how? Answer to these points are reviewed here.
The method here envisaged for updating maps at small scales has been applied in Central Spain to the Provincial Map of Madrid made by Instituto Geográfico y Catastral at scale 1:200,000.

2. ACCURACY OF LANDSAT MSS DATA

MSS data furnished by NASA for this project were both in photographic and digital form. In the first case 70 mm negative transparencies were available in a multitemporal coverage over Central Spain; in the second case, magnetic tapes requested have been provided to the investigator in standard CCT format, 9 track, 800 bpi. This material was analyzed for determining and improving its cartographic accuracy.

2.1. Photographic analysis

Bulk LANDSAT transparencies can be positioned in an absolute reference system by means of the indicators they contain in the margin. Such marks, although being able to serve for positioning any point in latitude/longitude geographical coordinates, do not seem to achieve the required cartographic accuracy for mapping purposes at small scales. If errors as large as 2 kms can be easily committed, the value of LANDSAT images by themselves as cartographic document should only be applied at scales smaller than 1:5,000,000 (according to the U.S. National Mapping Accuracy Standards - NMAS). As example in figure 1 is presented the grid of reference in image 2187-10143, which could be used as a mapping system independent of ground control. The image has also marginal indicators which allow to position it in polar stereographic coordinates.

In the intent to refer one single LANDSAT image to a conventional map projection the Universal Transverse Mercator (UTM) grid
Figure 1.—Absolute reference system existing on LANDSAT images by means of marginal indicators of geographical coordinates
was adopted for this analysis, with the purpose of defining positional errors. As it is known, such errors have a value in the order of 200 to 450 m. The selection of control points for this purpose was done according to criteria of good identification in enlarged LANDSAT images and in the basic reference system used. Also, measurements were done on the Provincial Map of Madrid at scale 1:200,000, with the intention of determining its cartographic accuracy or need for being updated.

As basic reference system it was used the National Topographic Map (N.T.M.) at scale 1:50,000, where control points have been identified in geographical coordinates \((\lambda, \varphi)\). This map has 1,130 sheets covering all the country and it is finished since the year 1958.

The N.T.M. was done in polyedric projection with every sheet limited by 20 minutes of arc of meridian and 10 minutes of arc of parallel, by reference to the ellipsoid of Struve. Recently, the UTM grid referred to the international ellipsoid of Hayford was adopted for the N.T.M. Such map, being produced and printed by Instituto Geográfico y Catastral, has allowed an accuracy in location of control points of 1" of arc for the longitude and 0.5" of arc for the latitude.

Typical control points were dams in reservoirs, intersection of roads and rivers, etc. In figure 2 is presented the spatial distribution of such points around Madrid province.

Conversion of geographical coordinates to U.T.M. was done before obtaining real distances between control points. Such calculation was effected by the known formulas:

\[
X = 500,000 + (IV)p + (V)p^3 + B_5
\]

\[
Y = (I) + (II)p^2 + (III)p^4 + A_6
\]

\[
p = 0,0001 \Delta M''
\]
Figure 2.—Spatial distribution of control points around Madrid province
which are referred to the international ellipsoid of Hayford. The value of each term can be found in reference 1, being \( X \) and \( Y \) the UTM coordinates of the control point.

The transfer of control points to the image presented problems of scaling in the different images tested at 1:500,000. As a multitemporal coverage of the area of control points was available, the following images have been measured:

\[
\begin{align*}
E & - 2403 - 10113 \\
E & - 2187 - 10143 \\
E & - 2169 - 10145 \\
E & - 2223 - 10135 \\
\end{align*}
\]

Table 1 summarizes the results obtained from this analysis, with indication of the control points positioned in figure 2 and explanation of their nature. The computations were done by measurement of the following distances:

\[
\text{MAP} - \text{REAL} \quad \text{or} \quad \text{LANDSAT} - \text{REAL}
\]

The absolute values in LANDSAT measurements indicate RMS (root-mean square) errors in each observation done on the four images above mentioned. Distances to points \( J_1 \) and \( J_2 \) could not be measured on the Provincial Map, because their location out of it.

As it can be seen from table 1, the Provincial Map of Madrid has a need for being updated, because the high values of the errors obtained by measurement of distances between control points located in rivers intersections or meanders. Such points (in the lower part of the table \( F_7, K_5, E_5, G_7, H_5, B_6, E_6, C_6 \) and \( H_6 \)) produce an error much larger than the tolerance of the map; thus their position is not accurately represented on it, as they correspond to natural features with dynamic change.
<table>
<thead>
<tr>
<th>POINTS</th>
<th>ERROR DISTANCES(m) MAP-REAL</th>
<th>ERROR DISTANCES(m) LANDSAT-REAL</th>
<th>CONCEPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₁ - B₁</td>
<td>35</td>
<td>46</td>
<td>C₁ = dam reservoir Pinilla, B₁ = dam reservoir Riosequillo</td>
</tr>
<tr>
<td>C₁ - D₁</td>
<td>21</td>
<td>308</td>
<td>C₁ = dam reservoir Pinilla, D₁ = dam reservoir Vellón</td>
</tr>
<tr>
<td>B₁ - D₂</td>
<td>53</td>
<td>274</td>
<td>B₂ = dam reservoir Riosequillo, D₂ = rivers intersection</td>
</tr>
<tr>
<td>A₂ - D₂</td>
<td>33</td>
<td>477</td>
<td>A₂ = rivers intersection, D₂ = rivers intersection</td>
</tr>
<tr>
<td>D₄ - F₄</td>
<td>62</td>
<td>139</td>
<td>D₄ = dam reservoir Los Arroyos, F₄ = river intersection</td>
</tr>
<tr>
<td>F₄ - H₄</td>
<td>18</td>
<td>159</td>
<td>F₄ = rivers intersection, H₄ = river/road intersection</td>
</tr>
<tr>
<td>D₇ - F₇</td>
<td>93</td>
<td>348</td>
<td>D₇ = river/road intersection, F₇ = rivers intersection</td>
</tr>
<tr>
<td>K₅ - E₅</td>
<td>431</td>
<td>349</td>
<td>K₅ = rivers intersection, E₅ = rivers intersection</td>
</tr>
<tr>
<td>C₇ - G₇</td>
<td>413</td>
<td>199</td>
<td>C₇ = hill of Los Angeles, G₇ = river meander</td>
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<tr>
<td>D₅ - H₅</td>
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<td>444</td>
<td>D₅ = lake of Retiro, H₅ = rivers intersection</td>
</tr>
<tr>
<td>B₆ - E₆</td>
<td>231</td>
<td>233</td>
<td>B₆ = river meander, E₆ = river meander</td>
</tr>
<tr>
<td>C₆ - H₆</td>
<td>103</td>
<td>103</td>
<td>C₆ = river meander, H₆ = river meander</td>
</tr>
<tr>
<td>J₁ - J₂</td>
<td>---</td>
<td>417</td>
<td>J₁ = rivers intersection, J₂ = dam reservoir Buenfía</td>
</tr>
<tr>
<td>J₂ - C₁</td>
<td>---</td>
<td>476</td>
<td>J₂ = dam reservoir Buenfía, C₁ = dam reservoir Pinilla</td>
</tr>
<tr>
<td>J₁ - C₁</td>
<td>---</td>
<td>218</td>
<td>J₁ = rivers intersection, C₁ = dam reservoir Pinilla</td>
</tr>
</tbody>
</table>

**TABLE I:** Comparison of results obtained by measurement of real distances between control points in U.T.M. coordinates, in the Provincial Map of Madrid at scale 1:200,000, and in LANDSAT images at scale 1:500,000 without correction (bulk data).
When control points in the map correspond to man made features, like dams in reservoirs or intersections with roads, the errors appearing on the map are much lower and they meet the cartographic requirements at such scale.

LANDSAT images can benefit from selection of the control points above rejected, assuming that they have a good identification on the basic cartographic reference system (in this case, the N.T.M. at scale 1:50,000).

According to NMAS requirements, mapping planimetric data has to be done with an error minor than 0.5 mm (0.02 inch), measured on the publication scale in 90% of well-defined features. Thus, for scale 1:1,000,000 the 90% accuracy value is therefore \( \sim 500 \text{m} \) on the ground, \( \sim 250 \text{m} \) at scale 1:500,000 and \( \sim 100 \text{m} \) at scale 1:200,000. As map errors may not be normally distributed, for practical purposes the RMS error of position for points tested should be less than 300 \( \text{m} \) at 1:1,000,000 scale, 150 \( \text{m} \) at 1:500,000, and 60 \( \text{m} \) at scale 1:200,000 to meet NMAS.

If this is so, from table 1 it can be established that bulk LANDSAT MSS images do not meet the requirements of NMAS if being referred to a U.T.M. projection for mapping purposes at small scales. Bulk images could only meet such requirements at scales of 1,000,000 or smaller.

2.2. Digital analysis

Once determined that bulk LANDSAT enlarged images at scale 1:500,000 over Central Spain do not meet the NMAS requirements for planimetric mapping in U.T.M. projection, an analysis of digital data was carried out for defining the necessary geometric corrections to be done on them before being applied to cartography at small scales. This procedure needed computer programming and associated hardware, as well as electronic printing of the corrected CCTs.
2.2.1. Registration: This work was conducted through IBM-Scientific Center of the Autonomous University of Madrid, where ERMAN-II program is available on an IBM 360/65 computer interfaced to an interactive television terminal RAMTEK. This powerful software has the capability of geometrically correcting an original NASA CCT, supplying with an output tape where the pixel is positioned in U.T.M. coordinates and it is converted from rectangular to square format representing 80 m x 80 m at the earth surface. This is done through the REGISTRATION program, which was used for the purpose of this investigation. Registration program needs control points of well known geographical coordinates to be introduced through the television terminal via cursor. As the program adjusts only a maximum matrix of 1000 x 1000 pixels at one time, the original CCT E-2187-10143 (3240x2340 pixels) was divided in the subscenes indicated at figure 3; where all together cover the province of Madrid in mosaic and each one has at least a 10% overlap.

In each subscene were obtained geographical coordinates of well known control points (a minimum of 6 in each one), taken from the N.T.M. at scale 1:50,000.

As input information to the program were also used the geographical coordinates of the corners of each subscene and its digital coordinates (by digital coordinates it is understood here line and pixel at the upper left corner of the subscene, number of lines and number of pixels to be loaded). Digital coordinates were approximately obtained by interpolation in b&w LANDSAT images at scale 1:500,000, while geographical coordinates were also approximately extracted from the same photographic document, once drawn its grid of parallels and meridians (figure 1). Both types of coordinates are required only approximately as indicator of the area of study to display
Figure 3.—Subscenes selected in Madrid province for geometric correction of MSS digital data
through TV terminal, because the corners of the subscenes never enter as control points in the registration programs.

Geographical coordinates of control points were entered in the computer through the RAMTEK terminal by conversational console via cursor, once the subscene had been displayed in false color at the TV screen and the control points has been identified on it.

Identification of control points was done following some practical rules for reducing errors in their location at the TV terminal, which seems to be critical if an accurate registration is required.

The identification of control points in the TV screen has to be done before locating them in the reference map and obtaining their geographical coordinates. At this point, a magnification factor of the display can be used for selecting those points of good definition (this concept involves considerations on the contrast and texture of the area under study). It is agreed that man made features produce much accurate identification of control points than natural phenomenal, namely if the points correspond to intersections of linear structures, like highways, airfields, corner of dams in reservoirs, etc.

As the TV display can be done at an scale comparative to the reference map used for positioning control points, bulk LANDSAT enlarged images do not need to be used at this step, and the definition of the points benefits from a much better accuracy than the obtained by positioning them on the satellite photographic product.

All these considerations apply only to the area of study in this project; the Central Region of Spain, where a good geodetic network exists, the basic reference map has good cartographic
accuracy being maintained up to date, and where there are many
man made features to be taken as control points. In a remote
area without cartography, the overall accuracy of this digital
analysis should be reduced.

Before doing registration of a LANDSAT CCT, the instantaneous
field of view of MSS sensor represent a nominal 79 m square,
even though it prints out at about 79 m by 56 m due to a pixel
overlap in the cross-track direction. After the registration
is run, the output pixel is squared at 80x80 m (on the ground).

Registration program applies a polynomial algorithm \(P(x,y)\) to
correct original pixels to their new position in lines, and a
second polynomial algorithm \(G(x,y)\) is used for positioning
them in columns, according to an U.T.M. grid adjusted to the
subscene by means of the entered control points. The degree of
the polynomial depends on the number of control points used
for each subscene. Table 2 shows their minimum number in each
case.

<table>
<thead>
<tr>
<th>polynomial degree</th>
<th>minimum control points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
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<tr>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 2.

Geometric correction of a matrix of 1000x1000 pixels requires
about 15 minutes of C.P.U. At the end of such operation geo-
 graphical coordinates of control points are displayed at the
TV screen, with indication of their residual values after the
<table>
<thead>
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<th>CONSOLE</th>
</tr>
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<tbody>
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<tr>
<td>0 0 0 0</td>
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<tr>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>

### Table: Registration-Point Evaluation Display for Run 7

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<thead>
<tr>
<th>ID</th>
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<th>PIXEL</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>RESIDUAL IN X</th>
<th>Y</th>
<th>R</th>
<th>FIT</th>
<th>ARDC</th>
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</thead>
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<td>1516</td>
<td>40010599</td>
<td>99N,003018012,99W</td>
<td>0 0 0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1101</td>
<td>1675</td>
<td>40005018</td>
<td>99N,003010929,99W</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>1795</td>
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</tr>
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<tr>
<td>6</td>
<td>1260</td>
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<td>99N,003020010,99W</td>
<td>0 0 0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4.*—Computer printout of geographical coordinates of control points used for correcting geometrically the subscene 15. Value of residuals are also indicated.
registration was run. The residuals are digitally measured in X and Y directions, as well as in radius vector. Figure 4 shows a computer printout of the geographical coordinates of control points introduced for correcting geometrically the tape 15 (see figure 2). In figure 4, residuals are zero; which means that an accurate identification and positioning of points has been obtained. If residuals were not null, the instantaneous field of view of MSS sensor does not allow an error of one pixel when the information is required for small scales mapping, specially at 1:200,000. At such scale residuals must be zero in order to meet NMAS planimetric requirements. In this situation, a new registration could be run on the resulting tape, with new control points, until errors eliminated. Such interactive mode of operation provides at the end to the investigator with a tape geometrically corrected by reference to UTM projection system.

As it can be seen in figure 4, a total of 7 control points and a second order algorithm were used for tape 15. The registration program assumes that the mean latitude of the image under study is N40 degrees. This value was introduced in the program as being the parallel of Madrid, and it was taken as mean value for all LANDSAT images over Central Spain. Figure 5 shows a flow-diagram of the registration program here applied for cartographic purposes.

In general more geometric accuracy was obtained in the registration process when control points were located near the borders of the image. It is more exact to register with a few points near the corners than with many points in the center of the image. More accuracy was also obtained by the use of a first order polynomial algorithm than by a second order algorithm. Residual errors seem to be smaller in the first case.
Figure 5.—Flow-diagram of the registration program used in cartography
Continuing with the digital analysis of LANDSAT information applied to cartography, as an option of the registration program a mapping movement vector menu was obtained through TV terminal display for all the subscenes. In figure 6 is shown the menu corresponding to tape E5. Such menu presents the displacements of 16 regularly distributed pixels of the subscene under study, once their position has been obtained in U.T.M. coordinates through registration program. As it can be seen in figure 6 there is a general movement of pixels in the image looking like a rotation once registered. Although it cannot be defined any accurate measurement of distances or angles through the television display presented in figure 6, the value of the longest vector on the display (19 lines and 23 pixels long) could be indicator, as well as the general movement of rotation-like, of any systematic error in the recording of the original CCT. In any case, it can be seen from figure 6 that the geometry of MSS data presents linear and angular anamorphosis when referred to a mapping projection system. This result is in accordance with the errors obtained by photographic analysis of LANDSAT information.

As the output pixel size is square of 80 m side, and the NMAS requirement for mapping at scale 1:200,000 is a RMS error of about 60 m, assuming that a perfect registration was done LANDSAT data do not guarantee at such scale the necessary cartographic accuracy; however, when a basic topographic location of the items in the map to be updated exists LANDSAT information can be used for updating works with cartographic accuracy at such scale. Also, LANDSAT registered data referred to U.T.M. projection do meet the NMAS requirements for planimetric mapping at scales 1:500,000.
THE LONGEST VECTOR ON THIS DISPLAY IS 19 LINES AND 25 PIXELS LONG

Fig. 6.—Mapping movement vector menu
**IMD LATITUDE / LONGITUDE TABLE**

**IMAGE NAME**

**ENTER POINTS**
- VIA CURSOR - CURSOR POINTS THEN EOF, EDT
- VIA KEYBOARD - EOF THEN ENTER POINTS, EDT

<table>
<thead>
<tr>
<th>POINT</th>
<th>LINE</th>
<th>PIXEL</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>1</td>
<td>39 59.31</td>
<td>25N</td>
</tr>
<tr>
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<td>467</td>
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<td>4</td>
<td>745</td>
<td>597</td>
<td>40 31.02</td>
<td>00N</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>593</td>
<td>39 59.22</td>
<td>22.89N</td>
</tr>
</tbody>
</table>

Fig. 7.—Geographical coordinates of the corners of the subscene 15, once geometrically corrected.
As random angular and linear anamorphosis exist in the original geometry of MSS data, when two original overlapping CCTs were intended to be geometrically positioned by reference to each other, this should not be possible unless the tapes were also registered and referred to a geodetic conformal projection. In such case, a digitally controlled mosaic of an area could be obtained, although the convergence of meridians could be influencing the accuracy of registration if the latitude of the images varied.

Finally, in figure 7 is indicated the menu corresponding to geographical coordinates of the corners of the subscene I5, once geometrically corrected.

2.2.2. Conversion to image. After referencing the original CCT to a geodetic projection, a new tape (or subscene) is obtained, which has to be converted into image. This could be done by means of CRTs, Electron Beam Recorders, Laser Beam Recorders or other electronic devices. In any case, the photographic product obtained can be considered as having the conformity of the geodetic projection and it does not present degraded quality, being able for reproductions larger than 1:500,000.

In this project tape to image conversion was done with a DICOMED D-47 film recorder operational at Instituto Geográfico y Catastral, interfaced to a PDP 11/45 computer (32K). The output products were 70 mm format transparencies in false color representing subscenes of nominal 1000 x 1000 pixels once registered to UTM projection (see figure 8).

Before entering the film recorder tapes must be reformatted to be made compatible with it, which accepts either of both 6 or 8 bits. Also, recording of channels is done in one file
Figure 8.—DICOMED D-47 film recorder

Figure 9.—Plotting matrix measurement definitions

ARRAY GEOMETRICS

- $H_1$ = Length of top horizontal line
- $H_2$ = Length of horizontal major axis
- $H_3$ = Length of bottom horizontal line
- $V_1$ = Length of left vertical line
- $V_2$ = Length of vertical major axis
- $V_3$ = Length of right vertical line
- $M_1$ = Length of matrix diagonal (0, 0 to max., max.)
- $M_2$ = Length of matrix diagonal (0, max. to max., 0)
- $L$ = Direction of scan line
each, with one register per line and in sequential mode for bands 4, 5 and 7 or 7,5 and 4. That way the film recorder runs the color image automatically controlling the color filters applied to each band. For the purpose of this project registered tapes were run at 8 bits (this applies to all four channels), by interleaving zeros in the expanded radiometric range to 255 levels of intensity.

The radiometric corrections applied to registered tapes before conversion to image have the objective of enhancing the output image to be photointerpreted. Techniques used normally involve equalization of histograms, although such radiometric corrections are not intended for pattern recognition because the change introduced in the radiometric balance of the data. This subject is discussed in another section of this final report (see Digital Processing, references 2).

Tapes converted to images have been run in linear mode according to NASA original recording, although they could be run in logarithmic mode by hardware configuration of the DICOMED recorder. In such case, the resultant increase in contrast could be reduced by a different internal calibration according to the type of film used, or by photographic processing.

Geometric accuracy of the DICOMED film recorder is defined by reference to the plotting matrix indicated in figure 9. It concerns the following concepts and values (reference 3):

- Orthogonality (O)
  \[ \pm 0,25\% \text{ of horizontal and vertical axes}\]  \(\% = \pm \left[ \frac{M_1 - M_2}{M_1 + M_2} \right] \times 100 \)

- Linearity (L)
  \[ \pm 0,35\% \text{ of the major axis}\]  \(L_H(\%) = \pm \frac{S_{vmax} - S_{vmin}}{2Hc} \times 100 \)
  \(L_V(\%) = \pm \frac{S_{vmax} - S_{vmin}}{2Vc} \times 100 \)

\(S = \) length of segments along the major axis
- **Line curvature (P)**
  \( P(\%) = \pm \frac{d}{L} \times 100 \)
  
  \( d = \) deviation from best fit straight line
  
  \( L = \) length of the major axis (Hc or Vc)

- **Trapezoiding (T)**
  \( T_H(\%) = \pm \left[ \frac{H_1 - H_2}{H_1 + H_2} \right] \times 100 \)
  
  \( T_V(\%) = \pm \left[ \frac{V_1 - V_2}{V_1 + V_2} \right] \times 100 \)

  \( T_H \) and \( T_V \) are the horizontal and vertical axes respectively.

- **Rectangularity (R)**
  \( R(\%) = \pm \left[ \frac{H_c - V_c}{H_c + V_c} \right] \times 100 \)

- **Spatial repeatability (S)**
  \( S(\%) = \pm \frac{d}{L} \times 100 \)

  \( d \) is the deviation of a point and \( L \) is length of the major axis (Hc or Vc)

In this project several images have been obtained through the film recorder providing valuable data to be photointerpreted in multidisciplinary mode. Some of them are shown in the section of digital processing (reference 2) or herein enclosed (figure 12). In none of them was observed a geometric distortion of the film recorder. On the contrary, such images have been used as a valuable cartographic document in the analysis of LANDSAT data over Central Spain. In any case, analog input signals generated by the D/A converters (figure 10), can be appropriately modified and then be sent to the deflection control circuits for complying with the geometric requirements above mentioned (in parenthesis is shown their maximum relative value).

Scale of the image obtained is result of the resolution mode
Figure 10.—Simplified block diagram of the DICOMED D-47 film recorder

Figure 11.—Resolution modes available in the DICOMED D-47 film recorder
used in the film recorder, which has three operational modes: high, medium and low (figure 11). High resolution assigns one pixel to a single point, medium resolution assigns one pixel to four points of equal intensity and low resolution provides an assignment of 16 points. Thus, the various resolutions provide either a 1 by 1, 2 by 2, or 4 by 4 points per pixel format. This feature permits a small scale image array to be recorded at a larger scale.

Although registered tapes could be run in any of such modes, for cartographic purposes there is a need of enlarging the image obtained, and the enlargement factor depends on the mode of resolution used. As the LANDSAT photographic document was intended to be enlarged at scale 1:200,000, the high resolution option could not be used in this project because the limit imposed by the enlargement factor. If the size of the registered subscenes has a maximum nominal value of 1,000 x 1,000 pixels, (80 x 80 kms on the ground), at scale 1:200,000 the enlargement factor should be about 40X. Thus, the film recorder was run at low resolution, although such mode degrades the image because the overlap existing between pixels (in that way enlargement factor to scale 1:200,000 was reduced to 10X).

When printing a LANDSAT registered image through the film recorder every pixel is square and the recorded tape represents a rectangular area on the ground of sides parallel to the X - Y axes in the UTM projection. The output image obtained through the DICOMED recorder has its X - Y local axes also parallels to the axes of U.T.M. projection. If the LANDSAT tape to be recorded was not registered or it was an original NASA OCT (conveniently preprocessed to be compatible with the CRT format), its conversion to image should destroy the geometric fidelity of the bulk scene, because the image skew for compensation of
Fig. 12. False colour image of Madrid-Aranjuez, corresponding to image 15. Original at scale 1:200,000, here reproduced at 60% of size. The image is geometrically corrected in U.T.M. Projection. Coordinates of control points are indicated in figure.
Earth rotation would disappear in the output product. This effect can be eliminated by internal reformat of the digital tapes.

Although pixels are squares of 79 m in MSS data, they are printed out in bulk processing as rectangles of 79 x 56 m. Such requirements can be accomplished when an original CCT (conveniently reformatted) is converted to image by the film recorder. This is possible with an optional hardware configuration of the equipment (manually changed), which is called "ERTS Aspect Ratio Option". It maintains the spot size circular at high resolution; but separates the printing distance of horizontal lines in a mode which produces a 54 x 54 mm square format of the exposed area representing 3240x2340 pixels (a full CCT).

As result of these above mentioned modes of operation with the film recorder, all the subscenes indicated in figure 3 were converted to a photographic document in false color, on positive color Ektachrome Daylight 6115 film. Processing of this film is not envisaged by Instituto Geográfico y Catastral, but it was done by PIX Laboratories S.A. in Madrid. Every subscene was recorded on a color transparency of cut film 4" x 5" at low resolution. Such document, representing on the ground a nominal area of 80 x 80 kms in UTM projection, was used as the basic document to be photointerpreted for cartographic purposes.

When the transparency was enlarged at scale 1:200,000 it was not possible to find out errors in the positioning of control points when referred to UTM projection. In figure 12 is observed the subscene I5 registered and enlarged. It represents in false color (4 = blue, 5 = green, 7 = red) the city of Madrid and the irrigation lands of Jarama, Tajo and Tajuña rivers, once the MSS data contained on it had been digitally positioned, by
means of ground control points, in UTM projection. Documents like this one have been used for updating the Provincial Map of Madrid at scale 1:200,000. The geographical coordinates of the five corner points of figure 12, once geometrically corrected, were indicated in figure 7.

As result of this digital analysis of LANDSAT data it has been defined their capability to be geometrically corrected and referenced to an UTM projection by means of well known ground control points; being the new image able to be used as a cartographic document for updating maps at small scales.

3. UPDATING MAPS AT SMALL SCALES

In paragraph 2 it was confirmed the capability of LANDSAT digital data for meeting the cartographic requirements of maps at small scales, once the images had been geometrically corrected and positioned in a geodetic reference system by means of control points. As result of the digital analysis of data, a methodology was established for updating maps at small scales. Figure 13 represents the diagram of operations used with LANDSAT information when being applied to updating maps at scale 1:200,000. All steps indicated in figure 13 have been widely commented before, and only the photointerpretation work is considered here.

Once the original transparencies had been registered and obtained through the film recorder, their enlargement to scale 1:200,000 could be done by optical projection or by photographic processing. In the first case it was used a DOT additive color composite viewer with change scale option, which projected on horizontal screen the enlarged image. The map was directly updated by transparency when positioned on
LANDSAT MAGNETIC TAPES

COMPUTER PROCESSING

LANDSAT 70 mm. TRANSPARENCIES

ENLARGEMENT SCALE 1:500,000

EXISTING MAPS

HISTOGRAM CORRECTION LOCATION OF CONTROL POINTS

INTERACTIVE TELEVISION TERMINAL

CONVERSION OF TAPES TO IMAGES

DICOMED D-47 FILM RECORDER

REGISTERED IMAGES AT SCALE 1:200,000

ENLARGEMENT FALSE COLOR

PHOTOINTERPRETATION

SCALE 1:200,000

UPDATED MAPS

Figure 13.—Diagram of operations used for updating maps at scale 1:200,000
the screen. In the second case, photographic enlargement of the false color original transparency obtained through the DICOMED film recorder was done on Cibachrome color paper and P-18 chemicals.

Both methods have shown the same accuracy for small scale mapping purposes, although the color composite viewer eliminates the need of photographic enlargement of the original transparency. Furthermore, the viewer permits obtaining a rough draft of the map to be delineated at a later stage by conventional cartographic techniques.

It is considered that producing and updating maps at small scales should require registration of each image at one time (3240x2340 pixels), with control points mainly located in the corners, and a first or second order algorithm of transformation. This work will be done in the future through IBM-Scientific Center of the Autonomous University of Madrid. At the moment registration was done for this project, taking the Province of Madrid as target, by 6 control points every subscene of 1000x1000 pixels, which is a prohibitive way of work in the future if a national coverage of LANDSAT registered tapes is required for small scales working purposes.

Although the need of using LANDSAT data in digital form as input to a cartographic system in Spain, some comparative considerations are indicated here, showing the goodness of such space acquired imagery as a valuable working tool. Let us consider a photogrammetric survey at scale 1:30,000 by conventional aerial techniques. Every image, in format of 21'5 x 21'5 cms, should have a 60% overlap along the flight direction and 30% side overlap. In the case of Spain a total of 35,000 photograms should be required for a total coverage of the national territory. The same coverage could be obtained
<table>
<thead>
<tr>
<th>Main surficial features</th>
<th>Best bands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>MAN</td>
<td></td>
</tr>
<tr>
<td>transportation network</td>
<td></td>
</tr>
<tr>
<td>airports</td>
<td>X</td>
</tr>
<tr>
<td>ports</td>
<td>X</td>
</tr>
<tr>
<td>excavations</td>
<td>X</td>
</tr>
<tr>
<td>WATER</td>
<td></td>
</tr>
<tr>
<td>coast profiles</td>
<td></td>
</tr>
<tr>
<td>reservoirs, lakes</td>
<td></td>
</tr>
<tr>
<td>rivers, channels</td>
<td></td>
</tr>
<tr>
<td>snow</td>
<td>X</td>
</tr>
<tr>
<td>pollution</td>
<td>X</td>
</tr>
<tr>
<td>irrigation network</td>
<td>X</td>
</tr>
<tr>
<td>VEGETATION</td>
<td></td>
</tr>
<tr>
<td>Coniferae</td>
<td></td>
</tr>
<tr>
<td>Quercus</td>
<td></td>
</tr>
<tr>
<td>fertile lowlands</td>
<td></td>
</tr>
<tr>
<td>rangelands</td>
<td></td>
</tr>
<tr>
<td>GEOMORPHOLOGY</td>
<td></td>
</tr>
<tr>
<td>drainage patterns</td>
<td></td>
</tr>
<tr>
<td>bare soils</td>
<td></td>
</tr>
<tr>
<td>sediment transport</td>
<td>X</td>
</tr>
<tr>
<td>marshlands</td>
<td>X</td>
</tr>
</tbody>
</table>

P.C. = false color

| SUM | 5 | 7 | 6 | 10 | 15 |

Table 3. Main surficial features identified by LANDSAT.
with less than 100 LANDSAT images, allowing a much more rapid updating of cartography at small scales, at a very lower price, and with the possibility of maintaining the information up to date.

In the case of Spain (504,750 kms\(^2\)), considering for a satellite mosaic covering the country the necessary images to be obtained over Portugal, Balearic and Canary Islands, South of France and North of Africa, and considering the side overlap of LANDSAT images at N40 degrees latitude, a total of 50 false color images should be required for a complete coverage of the National Map.

Once agreed that there is a need of LANDSAT data for cartographic purposes at small scales, an analysis was carried out for determining what can be detected on the satellite image that should be represented on the map. At this point, many scientific works have been done in the last years (in what could be called the early times of LANDSAT program), trying to identify by photointerpretation techniques "all" the information contained in a satellite image. And this is an exhaustive work, time changing, dependent of multitude of parameters, varying with the geographical location, etc. For cartographic purposes at small scales the working approach for determining what can be detected is a question of generalization of LANDSAT information.

Such generalization is intended for the purpose of defining what the cartographer has to look for in a LANDSAT image, with guarantee that the information "will be there" and it will be as invariant as possible. Factors like atmospheric conditions, sun angle elevation, date of observation, etc., will always modify the output product of a remote sensing system; but for operational purposes such modifications need to be centered around mean invariant values. Let us take as example of this invariant approach done by the cartographer the following
<table>
<thead>
<tr>
<th>Topographic items</th>
<th>LANDSAT detection</th>
<th>Topographic items</th>
<th>LANDSAT detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td></td>
<td>Hydrography</td>
<td></td>
</tr>
<tr>
<td>highways</td>
<td>yes</td>
<td>rivers</td>
<td>yes</td>
</tr>
<tr>
<td>in service</td>
<td>yes</td>
<td>dams, cascades</td>
<td>no</td>
</tr>
<tr>
<td>in construction</td>
<td>yes</td>
<td>lakes</td>
<td>yes</td>
</tr>
<tr>
<td>in project</td>
<td>no</td>
<td>marshlands</td>
<td>yes</td>
</tr>
<tr>
<td>one roadway</td>
<td>no</td>
<td>channels</td>
<td>no</td>
</tr>
<tr>
<td>main tolls</td>
<td>no</td>
<td>seashore</td>
<td>yes</td>
</tr>
<tr>
<td>principal roads</td>
<td>no</td>
<td>Habitated places</td>
<td></td>
</tr>
<tr>
<td>secondary roads</td>
<td>no</td>
<td>isolated houses</td>
<td>no</td>
</tr>
<tr>
<td>others</td>
<td>no</td>
<td>industrial plants</td>
<td>no</td>
</tr>
<tr>
<td>Railroads</td>
<td></td>
<td>airfields</td>
<td>no</td>
</tr>
<tr>
<td>two roads</td>
<td>no</td>
<td>cities</td>
<td></td>
</tr>
<tr>
<td>one road</td>
<td>no</td>
<td>more than 5,000 h.</td>
<td>yes</td>
</tr>
<tr>
<td>narrow-gages</td>
<td>no</td>
<td>from 3,000h. to 5,000h.</td>
<td>no</td>
</tr>
<tr>
<td>stations</td>
<td>no</td>
<td>less than 3,000 h.</td>
<td>no</td>
</tr>
<tr>
<td>tunnels</td>
<td>no</td>
<td>Vegetation</td>
<td></td>
</tr>
<tr>
<td>grade crossing</td>
<td>no</td>
<td>forests</td>
<td>yes</td>
</tr>
<tr>
<td>teleferics</td>
<td>no</td>
<td>Altimetric data</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Administrative limits</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 4. Topographic items appearing in a map at scale 1:500,000 and their identification by means of LANDSAT data.
case: it is scientifically recognized as a merit that a geologist says "I have discovered a fault in a LANDSAT image"; but a cartographer cannot say "I have discovered a highway", because highways must be positioned on his maps even before they are constructed. In other words, LANDSAT can provide valuable data of many surficial features, but only those data invariant and systematically identifiable can be considered by the cartographer.

In the intent of applying LANDSAT data to updating maps at small scales, a list has been established in table 3 containing the main surficial features identified at LANDSAT images when studied in Spain. Such table is based in experienced criteria of photointerpreters and gives a comparison of the capabilities of each spectral band and their false color combination for identifying the most relevant natural and artificial (man made) features.

As it can be seen from the sum of applications in each band, false color information is unique for identification of the natural cover of the earth surface, while band 7 is specially indicated when artificial features (man made) have to be located.

When talking about false color, it has to be understood as a combination of MSS bands 4, 5 and 7, which gives information in the spectral regions of the green, red and infrared; providing data not only in the visible spectrum but farther than the conventional color infrared photographic images.

Table 4 represents existing topographic items in a map at scale 1:500,000. Such information is agreed that "has to be on the map", no matter how LANDSAT data are able to identify it at the earth surface. Topographic items in table 4 were obtained from the existing european specifications for maps at scale 1:500,000, according to which the National Map of
<table>
<thead>
<tr>
<th>Topographic items</th>
<th>Time invariant</th>
<th>Best band</th>
<th>False color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>highways</td>
<td>yes</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>in service</td>
<td>yes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>in construction</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rivers</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lakes</td>
<td>yes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>marshlands</td>
<td>yes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>seashore</td>
<td>yes</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>cities</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>more than 5,000h.</td>
<td>yes</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>forests</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Sum                       | 3  | 3  | 2  | 7  | 7  |

Table 5. Combination of tables 3 and 4 showing topographic items identified by LANDSAT in any season (multitemporal detection).
Spain will be produced (reference 4). From the analysis of table 4 it can be defined in a certain way the capability of LANDSAT for supplying topographic data at the scale under study. The limitation of the satellite for defining many of the items indicated in the table comes from the MSS sensor resolution, which is not enough to provide many of the basic data required in the map at such scale. Resolution of corrected images is 80 x 80 m.

Continuing with the intention of defining invariant values to look at in a LANDSAT image, a combination of tables 3 and 4 was studied, looking for topographic items identifiable during the four seasons of the year. The result is shown in table 5, where cartographic information indicated is multi-temporal invariant. The meaning of this term multi-temporal has to be understood here in the way that, although changes occurring in the nature, such changes are always detectable by at least one of the MSS spectral bands at any time. As this research project was NASA supported, a multitemporal coverage of images over Central Spain was available for the purpose of this work.

Analysis of table 5 gives the following results:

1 - All items appearing in table 4 as detectable by LANDSAT show a multi-temporal capability for being identified. The reason is that resolution of the MSS sensor imposed in table 3 a much stronger limitation than the seasonal variation studied in table 5. From this, it can be stated that resolution is a more limitative factor than the temporal change of the surface cover for LANDSAT data applied to cartography at small scales.
2 - Band 7 shows the same detection capability than false color composites, according to the sum of different conventional signs identified. This result is different to the one presented in table 3, where false color information, when applied to cartography in general (including thematic mapping), was more able to discriminate natural phenomena. When the area of analysis is limited to topographic mapping, band 7 shows as good capability as false color information for discriminating different types of cartographic items.

3 - Band 7 and false color information can detect by themselves almost all the topographic items that MSS data can position in a map at scale 1:500,000. In the case of forests, better information is achieved from the color composite, while the infrared band gives more accuracy in the delineation of seashores. Except for these two items, their content of information seems to be similar, and both band 7 and the false color composites together can detect all the MSS information applicable to topographic mapping in Spain.

A comment must be given to the high capability of band 4 for detection of interrelations between water and land. From a topographic point of view border lines can be better recognized in band 7, as in the cases of seashores, marshlands and lakes. But band 4 is able to provide bathymetric information at low depths, while the infrared absorption of radiation in the water does not allow band 7 to give any data of the underwater configuration.

Another topographic item for interest is the detection of cities of more than 5,000 inhabitants. When a map at scale 1:500,000 is produced, the urban area has to be generalized from information at larger scales. Such generalization can be done
by means of LANDSAT data, as shown in the false color composite of Madrid appearing in figure 12. Bulk data in false color at scale 1:500,000 or larger do not allow by themselves to determine with cartographic accuracy the contours of even large cities. As an example of this can be indicated the land use map at scale 1:250,000 submitted within this final report, which was done by an experienced photointerpreter (reference 5). Comparing in the map the city of Madrid with the topographic map at scale 1:200,000 also enclosed herein (where the city was drawn by generalization of information at scale 1:25,000), it can be stated that LANDSAT does not offer enough information for determining urban contours with cartographic accuracy. Only if the urban area is represented schematically or by a conventional sign, should LANDSAT give enough accuracy for identification of cities. As such schemes or conventional signs are well represented in a map at small scale LANDSAT information was considered time invariant and able to detect cities in tables 5 and 4.

Cartography at small scales from LANDSAT data can be accomplished in three stages:

- acting of automatic cartography
- acting of LANDSAT information
- acting of conventional cartography

They are analyzed below.

3.1. Acting of automatic cartography.

Three main activities are indicated for this method of work:
- Drawing of the parallel and meridian canevas, and its exterior limit or frame
- Positioning of the main geodetic network, with its corresponding sign.
3.2. Acting of LANDSAT information.

As defined in paragraph 2, LANDSAT data have to be geometrically corrected and referenced to a geodetic projection for achieving cartographic accuracy. Corrected images can be used for mapping the positively identified items by LANDSAT indicated in Table 5: highways in service, highways in construction, rivers, lakes, marshlands, seashore, large cities and forests. All such items can be detected in any season from LANDSAT information and, what makes really useful the data, these cartographic items show a rapid change in the nature and they are able to be kept constantly up to date by means of multi-temporal MSS recordings.

Band 7 and false color composites can be used as unique working documents for topographic mapping, although every item could be better identified by different radiometric enhancement methods (reference 2).

3.3. Acting of conventional cartography.

All items indicated in Table 4 which did not show enough resolution or real pattern for LANDSAT detection have to be mapped by means of conventional cartographic techniques. At this point, ancillary information is required in the form of existing maps, field work, conventional aerial photography, etc. The
list of such items is indicated in table 6. Their position in a map cannot be systematically defined from LANDSAT satellites, unless resolution of the MSS sensor increased in the future.

<table>
<thead>
<tr>
<th>roads</th>
<th>dams, cascades</th>
</tr>
</thead>
<tbody>
<tr>
<td>main tolls</td>
<td>channels</td>
</tr>
<tr>
<td>railroads</td>
<td>isolated houses</td>
</tr>
<tr>
<td>stations</td>
<td>industrial plants</td>
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<td>tunnels</td>
<td>airfields</td>
</tr>
<tr>
<td>teleferics</td>
<td>small cities</td>
</tr>
<tr>
<td>grade crossing</td>
<td>altimetric data</td>
</tr>
<tr>
<td></td>
<td>administrative limits</td>
</tr>
</tbody>
</table>

Table 6.

Updating maps at small scales can benefit from the use of LANDSAT information, which can be considered as a powerful working tool existing in the space. Such information has several advantages, when applied to cartography, that guarantees its value and uniqueness. They are the following:

- possibility of a multitemporal coverage of the earth surface, providing the capability of maintaining the information up to date.
- more economic production and updating of cartography at small scales than by the use of conventional techniques.
- rapid way of work, with a strong reduction in the number of basic information other than LANDSAT required; allowing a faster mapping of large areas than by conventional techniques.
- invariance of the space information compared to the aerial images obtained by photogrammetric surveying. Such invariance
is concerned with format, scale, projection, distortion, orientation, etc.

- elimination of progressive errors generated by conventional techniques, when maps at small scales are obtained by generalization of large scale maps (1:25,000 1:50,000 1:200,000 1:500,000 1:1,000,000).

Because the limited resolution of the MSS sensor, only some topographic items can be identified systematically from LANDSAT data. Such items are important to be periodically recognized because their rapid natural (or artificial) change. The capability of LANDSAT information for defining topographic items of interest in a map at small scale is summarized in table 7.

| highways in service | marshlands |
| highways in construction | seashore |
| rivers | .large cities |
| lakes | forests |

Table 7.

Although MSS information is unique in the world, it cannot be used as the unique input for mapping at small scale; requiring ancillary information by conventional techniques in order to overcome the following limitative factors:

- not enough resolution for defining all the topographic items to be positioned in a map at small scale. Such not detectable items were indicated in table 6.

- absence of altimetric data, because the lack of a photogrammetric base in the observation system.
none indication of political or administrative limits, which have to be in the map and cannot be envisaged by any remote sensing system because their absence of physical patterns.

- need of geometric correction of the MSS data by reference to a geodetic projection before achieving the necessary cartographic accuracy.

4. THE NATIONAL MAPS AT SMALL SCALE.

LANDSAT information could be applied in Spain to updating the following small scale maps produced by Instituto Geográfico y Catastral:

- Provincial Maps at scale 1:200,000
- National Topographic Map at scale 1:500,000
- National Topographic Map at scale 1:1,000,000

At each scale the input LANDSAT information should be different, as it should be also the processing technique used and the cartographic work.

4.1. National Topographic Map at scale 1:1,000,000.

The interest of this scale is evident, and it is enough to remember that Spain was one of the ten countries attending the First International Conference of the World Map at scale 1:1,000,000, held at London in 1909.

Instituto Geográfico y Catastral has published several maps at such scale in basic topographic versions and for the purpose of thematic cartography. The last editions correspond to 1963 and 1974. In the edition of 1963, it was used a conformal conical projection of Lambert with two automecoic parallels at N36°40' and N39°20'. In the edition of 1974, it was used the same projection and the automecoic parallels used were at N37°10'41"058 and N42°49'18"942. Printing is done in six colors with twelve hypsometric inks. The map has level curves every 100 meters.
and shading relief. The basic work was done by photographic reduction and generalization of the National Topographic Map at scale 1:50,000.

According to the NMAS requirements, for practical purposes the RMS error of position in a map at such scale should be less than 300 m on the ground. From Table 1 it was obtained a mean value of the RMS errors in 90% of control points, when referencing LANDSAT images to UTM projection; being such value 278 m, which is of the same magnitude that the tolerance of the map.

As the mean value obtained has the same magnitude than the allowable RMS error, it can be said that LANDSAT bulk images referred to a UTM projection, when used for mapping purposes at scale 1:1,000,000, do not offer absolute guarantee of accuracy.

The most appropriate band for mapping at such scale should be band 7, as well as the false color composite. The items to be updated have been indicated in table 7.

As the National Map is in Lambert projection some scale corrections are needed on LANDSAT images, although in the case of Spain they would not be of influence at the mean latitude of N 40°, with the automecoic parallels chosen. It is not intended in this report to present the mathematical corrections that a Lambert projection should impose in the LANDSAT image, but some general remarks are indicated.

As the flight direction of the satellite is given as 9° west of south (being \( \cos 9° = 0.9988 \)), assuming a north-south track for this report, 184 kms of side in each photograph represents 1°40' of latitude. Along adjacent flight strips the east and west edges of the images would match because their same scale in north-south dimension (assuming that exposure positions would be at the same latitudes), being the maximum mismatches, therefore,
in the east-west direction at the joining edges of successive images in a flight strip.

In the image center at N40° latitude it could be obtained the scale factor and be compared to the factors of the upper and lower images in the same orbital pass, thus obtaining the scale factors of the northern and southern edges of each image and the expected errors in imagery matching at each join edge.

4.2. National Topographic Map at scale 1:500,000.

The National Topographic Map of Spain at scale 1:500,000 will be updated in the year 1977 with the sheet distribution indicated in figure 14. Such map will be produced extracting information from LANDSAT MSS data in digital tape when geometrically corrected by reference to the U.T.M. projection. The methods here indicated in paragraphs 2 and 3 will be used for this work.

The National Map will be produced according to the european specifications, although such standard procedure presents some problems in the particular case of Spain; like the color distribution of elevations and the location of the isohypse of 75 m. The light color distribution (yellowish-greenish tones) has been calculated according to the European mean elevation above sea level, which is lower than the existing in Spain. As result of this, the dominant color in the new map would be the dark brown, with low contrast of the cartographic information represented on it.

The scale 1:500,000 seems the most appropriate for cartographic application of LANDSAT data.

4.3. Provincial Maps at scale 1:200,000.

The Provincial Maps at scale 1:200,000 were made by generalization of information and reduction of the N.T.M. at scale 1:50,000,
Fig. 14.—Sheet distribution of the National Map at scale 1:500,000
which is in polyedric projection. Such map, as it was demonstrated from Table 1, does not meet the standard cartographic requirements, mainly because the wrong position of rivers and natural features which have changed in the last years.

The methodology for updating Provincial Maps should be the same that it was mentioned for the National Map at scale 1:500,000, by means of corrected LANDSAT digital data. As part of this project the Provincial Map of Madrid was updated from MSS digital information, and in this final report is presented the new edition of the map (folded in the back cover).

Several modifications have been introduced in the new map as compared to the old one. As new topographic and thematic items identified on it by means of LANDSAT can be indicated the following:
- one new urbanization (Tres Cantos)
- two golf course (Puerta de Hierro and Club de Campo)
- forests (with differentiation of conifers and leafy trees)
- irrigation lands (along Manzanares, Tajo, Tajuña and Jarama rivers)
- one new reservoir

Also, several main roads have been modified, the rivers layout, the toponymy and several other conventional signs. This map was made in a fast mode of operation by photointerpretation of the geometrically corrected images generated from MSS digital data.

5. CONCLUSIONS

In this report it has been evaluated the capability of LANDSAT MSS data for updating maps at small scales in Central Spain.

As stated in the analysis of cartographic accuracy done with LANDSAT data, the images themselves can be positioned in an
absolute reference system (geographical coordinates or polar stereographic coordinates) by means of their marginal indicators. Errors in this case do not allow a higher accuracy in positioning a point than 2 km; which is a value only able to use the images for mapping purposes at scale 1:5,000,000 or smaller.

By reference to a UTM projection, the errors (RMS), in bulk images could be in the order of 250 to 450 m. Such measurements were done by means of control points located in the images, and they do not allow MSS data to be used in cartography at such scale.

By digital analysis of LANDSAT data and geometric positioning of pixels in UTM projection, it was achieved and accuracy of the corrected MSS information which could be used for updating maps at scale 1:200,000 or smaller. The results here obtained show that adjustment of the UTM grid is better obtained by a first order, or even second order, algorithm of geometric correction.

In the selection of control points man made features exhibit better capability for an accurate registration than natural phenomena, which are normally wrongly positioned on small scale maps (as the Provincial Map of Madrid at scale 1:200,000) and present dynamic changes. The number of control points has influence in the accuracy of registration with a CCT. Also, their position near the border of images reduces residuals and the processing time of C.P.U. required in registration. If results do not meet the NMAS requirements for mapping purposes (which force an error of zero pixels at the current MSS resolution), the geometric correction of CCTs could be run interactively until a good result is achieved.

Positioning of independent CCTs to a common geodetic projection is required for elimination of the anamorphism existing in their bulk data, and for having benefit of the conformal properties of the projection. Such relative image to image geometric
relationship is possible by registration of the original MSS data, mainly with the purpose of constructing digitally controlled mosaics. Bulk data by themselves do not allow establishing this relative geometric relationship between independent CCTs.

Conversion of registered CCTs to image is a need if the information referred to UTM projection is to be photointerpreted for cartographic purposes. Geometric correction of the output false color image can be done by hardware configuration of the film recorder. Some limitations exist in the enlargement of the image, when it is going to be used for mapping at small scales, mainly concerned with degraded printing or enlarging factors. The output image maintains the cartographic fidelity of the registered CCT. As an option the false color image could be enlarged by projection. In that case better operational results can be obtained if projection is done on horizontal screen, allowing not only the photointerpretation but the drawing of the rough draft transparency of the map to be updated.

LANDSAT information is needed when a map at small scales is desired to be kept up to date. MSS data allow a faster and more economic cartographic work, being limited by the resolving power of the sensor. For cartographic purposes only clearly and systematically detectable features can be taken into consideration when using LANDSAT data as input. In any case, it is required ancillary information when producing or updating a map. Such information concerns conventional cartography and aerial photography. Table 7 summarizes the items able to be updated by LANDSAT.

Band 7 and false color composites exhibit the best capability in cartography, being their content of information for such application very similar, except in the case of water features detection (band 7 gives better results) and in forest identification (false color is required).
When applying these considerations to the National Topographic Maps, the goodness of LANDSAT information shows dependent on the scale. At scale 1:1,000,000 a use of bulk data referred to an UTM projection system could be done, providing data of all the national territory, although the cartographic accuracy of such MSS data is not guaranteed. The use of a conformal Lambert projection should not modify significantly the application at this scale.

The methodology for updating maps at scales 1:500,000 and 1:200,000 is similar and there is only a difference in the enlargement factor applied to the geometrically corrected image to be photointerpreted. As example of this operational use of LANDSAT data it has been updated the Provincial Map of Madrid at scale 1:200,000. This procedure required geometric correction of digital data by means of control points referred to UTM projection.

Finally, from this evaluation of MSS information applied to updating cartography, it can be stated the need of better resolution and spectral bands in the sensor, if LANDSAT program will follow-on in the future with the objective of providing systematic data to be used, not only in an experimental stage, but for operational purposes.

Aknowledgement.

Aknowledgement is given to Dr. Montoto, of IBM - Scientific Center, for his support in the geometric correction of MSS digital data.

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DIGITAL PROCESSING

STUDY OF RADIOMETRIC ENHANCEMENT METHODS APPLIED TO LANDSAT MSS IMAGES.

A. Santisteban

DETERMINATION OF UNCORRELATED BANDS IN A LANDSAT MSS IMAGE.

A. Santisteban

THE BAND RATIOING TECHNIQUE APPLIED TO LANDSAT MSS IMAGES.

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1. INTRODUCTION

It is well known that the human eye can not discriminate too many grey levels. In fact not so many as a microdensitometer, a multispectral scanner or any other image digitizing device can. Hence a digital image can show up quite a lot of information when studied numerically (for instance by some automatic classification computer program) while appearing nearly uniform or blurred to a photointerpreter who studies it as an output of a film recorder. Then some processing is needed in order to obtain from the original digital image a photographic printout more suited to the analytic capabilities of the human observer. This processing, known in general as radiometric enhancement, can be done either photographically or digitally. We will cover in this paper only the latter which is clearly a more versatile and powerful method\(^1\).

Most digital images are recorded on 9-track magnetic tapes and, for that reason, every picture element (pixel) is represented by 8-bits even if data actually consists of less bits. For instance\(^2\);\(^3\). LANDSAT MSS images delivered by NASA have 8 bits per pixel in every band although bands 4, 5 and 6 contain 7-bit data and band 7 contains 6-bit data. We must point out that the LANDSAT multispectral scanner gathers data of bands 4, 5 and 6 in 6-bit logarithmic scale; NASA translates them into a 7-bit linear scale according to calibration data: The differences of calibration among the six sensors of each band, along with the overall differences of calibration over a frame are responsible of the fact that more than 64 levels are occupied in the output bands.
In this paper we discuss the most useful methods of radiometric enhancement of digital images. In particular we apply these methods to LANDSAT multispectral scanner images, preparing them for recording using a DICOMED D-47 film recorder. This instrument accepts 6-bit and 8-bit data and can consider them as either linear or logarithmic scale data. We will consider only 8-bit linear output data because images delivered by NASA contain linear scale data and we take advantage of the greater number of output grey levels. We will also discuss briefly the use of the CONRAC RHN19 colour TV screen included in the RAMTEK GX 100B interactive display system as output device. It has only 16 levels in each electron gun, hence only 16 grey levels are available for the output.

In Section 2 of this paper we consider radiometric enhancement functions in general, while in Section 3 we mention the most useful practical cases that we apply to a practical example in Section 4. In Section 5 we discuss the application of different enhancement functions at the same time. Finally we make some considerations about colour images in Section 6.

2. RADIOMETRIC ENHANCEMENT FUNCTIONS

Let

$$J_n = \{ i \mid i \in \mathbb{Z}, 0 \leq i \leq 2^n - 1 \}, \quad n \in \mathbb{N}$$

(1)

be the subset of the integer numbers that can be written with \( n \) binary digits (bits). Then a (single band) digital image is a two-dimensional array of elements of some \( J_n \); the numbers \( i \in J_n \) represent the radiometric intensity levels of the corresponding pixels.

Any radiometric transformation of a digital image is a mapping

$$F : J_n \rightarrow J_m$$

(2)

of its set of radiometric levels into another (possibly different) set of levels. In particular we are concerned with a special kind of radiometric transformations: the so called radiometric enhancement that are not characterized by any mathematical property but by a subjective fact: they tend to facilitate the analysis of the image by a photointerpreter by means of a redistribution of the most relevant radiometric levels in a way more suited to the human eye tonal response, taking into account the performance of the image producing devices. The only mathematical condition that we impose is that the mapping must preserve an order relation of its original set in
Fig. 1. Histogram of the example image in logarithmic scale. (When $P(i) = 0$ is plotted $P(i) = 1$.)
its image $F(J_n) \subset J_m$, namely either

$$
\forall i, j \in J_n, \ i \leq j \Rightarrow F(i) \leq F(j)
$$

or

$$
\forall i, j \in J_n, \ i \leq j \Rightarrow F(i) \geq F(j)
$$

or, what amounts to the same, they must be monotonous mappings. In case of a decreasing monotonous mapping we say that we get a negative of the original image.

Despite its psychophysiological improving effect, radiometric enhancement usually degrades the image in the sense that increases its entropy or, conversely, loses information. Only when $F$ is a biunivocal mapping of

$$
J'_n = \{ i \mid i \in J_n, \ P(i) \neq 0 \} \subset J_n
$$

onto its image $F(J'_n) \subset J_m$, $P(i)$ being the number of pixels with radiometric level $i$, the transformation is isoentropic.

To prove the previous assertions we remember that the entropy $S$ and the information $I$ of an image are defined as

$$
S = -I = \sum_{i \in J_n} p(i) \log p(i)
$$

where

$$
p(i) = \frac{P(i)}{\sum_{i \in J_n} P(i)}
$$

log stands for logarithm of base 2 and $p(i) \log p(i)$ is taken as zero whenever $p(i) = 0$. Then, if $F(i) = F(j)$ with $i \neq j$, the fact that

$$
p(i) \log p(i) + p(j) \log p(j) \leq [p(i)+p(j)] \log[p(i) + p(j)]
$$

implies that the entropy increases when $p(i) \neq 0$, $p(j) \neq 0$.

3. SPECIAL ENHANCEMENT FUNCTIONS

Now we are going to discuss the most useful enhancement functions $F$ (see eq. (1)).

We consider that the histogram of the original image is the function

$$
P : J_n \rightarrow \{0\} \cup N
$$

and the histogram of the output image is the function
Fig. 2. Histogram of the image of a reservoir and its surroundings in logarithmic scale. There are two well separated lobes, one corresponding to the water and the other to the dry land.
Fig 3.—The original example image. (In fact the 6 bits of data are assigned the 5 more significant bits of the 8-bits scale of the film recorder.)
Fig 4.—Example image enhanced with $v = 4$
Fig. 5.—Example image enhanced with $v = 3$
and call $\mu$ and $\sigma$ the mean and standard deviation of the histogram $P(i)$:

$\mu = \frac{\sum_{i \in J} i \cdot P(i)}{\sum_{i \in J} P(i)}$ \hfill (9a)

$\sigma^2 = \frac{\sum_{i \in J} i^2 \cdot P(i)}{\sum_{i \in J} P(i)} - \mu^2$ \hfill (9b)

To simplify notation we introduce the rounding function

$e : \mathbb{R} \rightarrow \mathbb{Z}$ \hfill (10a)

defined as

$e(x) = \text{Int}(x + 0.5)$ \hfill (10b)

i.e. $e(x)$ is the biggest integer number smaller than or equal to $x + 0.5$.

3.1. Linear Function

The simplest enhancement function, and nearly the only one used, is the truncated linear (usually referred simply as linear), defined as

$L_1(i) = \begin{cases} 
0 & \text{if } ai + b \leq 0 \\
e(ai + b) & \text{if } 0 \leq ai + b \leq 2^m - 1 \\
2^m - 1 & \text{if } 2^m - 1 \leq ai + b
\end{cases}$ \hfill (11)

If we take

$a = \frac{\alpha}{\sigma}, \quad b = \beta - \alpha \frac{\mu}{\sigma}$ \hfill (12)

we obtain an image that, apart from the effect of the truncation due to the function $e$ and the cut off of the histogram tails, has mean $\beta$ and standard deviation $\alpha$.

This enhancement transformation gives very good results when the histogram (empty levels excluded) approaches a normal distribution or, at least, is approximately bell shaped (see Fig. 1).

A good parameter selection may be
Fig. 6 — Example image enhanced with $v = 2$
Fig. 7.—Example image enhanced with $v = 1$
\[
\alpha = \frac{2^m - 1}{2\nu}, \quad \beta = \frac{2^m - 1}{2},
\]

then
\[
\gamma = \frac{2^m - 1}{2\nu}, \quad \delta = \frac{2^m - 1}{2} \left(1 - \frac{\mu}{\nu}\right)
\]

and the output image has its mean at the center of the tonal range and the central peak of width \(2\nu\) of the histogram is assigned the whole range. All levels more than \(\nu\) standard deviations far from the mean are accumulated on the end values 0 and \(2^m - 1\). The value of \(\nu\) is a compromise between the need of high contrast (small \(\nu\)) and limitation of the degradation produced by the tail-cut off (big \(\nu\)).

### 3.2. Piecewise linear function.

When the histogram is not bell shaped at all but has several lobes (see Fig. 2) the linear transformation (11) may deteriorate the image, mainly if we want a high contrast. Then we can try a piecewise linear function. We may use a stiff segment for each lobe and a flatter one for the interlobe part:

\[
L_3(i) = \begin{cases} 
0 & \text{if } a_1i + b_1 < 0 \quad \text{and } 0 \leq i \leq c_1 \\
e(a_1i + b_1) & \text{if } 0 \leq a_1i + b_1 \leq 2^m - 1 \quad \text{and } 0 \leq i \leq c_1 \\
\text{e}(a_2i + b_2) & \text{if } 0 \leq a_2i + b_2 \leq 2^m - 1 \quad \text{and } c_1 \leq i \leq c_2 \\
\text{e}(a_3i + b_3) & \text{if } 0 \leq a_3i + b_3 \leq 2^m - 1 \quad \text{and } c_2 \leq i \leq 2^n - 1 \\
2^m - 1 & \text{if } 2^m - 1 \leq a_3i + b_3 \quad \text{and } c_2 \leq i \leq 2^n - 1
\end{cases}
\]

Obviously there are many (8 in this example) degrees of freedom in the construction of piecewise enhancement function: the gain and bias of each segment (remember that, though condition (3) must be satisfied, all gain and bias parameters are independent) and the break points \((c_1\) and \(c_2\) in equation (15)).

### 3.3. Approaches to the optimal information display.

Taking into account that \(J_n\) and \(J_m\) are sets of symbols for image coding, and the well known result of information theory that states that the optimum coding is the one in which all symbols have the same frequency, we are going to consider an approach to the optimal information transmission to the photointerpreter.
<table>
<thead>
<tr>
<th>Figure</th>
<th>$v$</th>
<th>$a$</th>
<th>$b$</th>
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<th>% pixels</th>
<th>Right tail levels</th>
<th>% pixels</th>
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<td>48 - 63</td>
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<td>0 - 22</td>
<td>19.22</td>
<td>33 - 63</td>
<td>13.66</td>
</tr>
</tbody>
</table>

**TABLE 1**

Parameters concerning figures 4 to 7
It is obvious that no mapping of $J_n$ into $J_m$ can induce the transformation of the histogram $P(i)$ into a flat histogram $Q(j)$ because

$$Q(j) = \begin{cases} P(F^{-1}(j)) & \text{if } j \in I_m(J_n) \\ 0 & \text{if } j \notin I_m(J_n) \end{cases}$$

Nevertheless we can distribute the continuous tonal range, i.e. the continuous interval $[0, 2^m - 1] \subseteq \mathbb{R}$, in $2^n$ ordered parts of lengths $d(i)$ proportional to $P(i)$;

$$d(i) = \frac{2^m - 1}{\sum_{j \in J_n} P(j)} P(i),$$

and construct the radiometric enhancement function $H$ that assigns to each $i \in J_n$ the integer number nearest to the middle point of the corresponding subintervals of $[0, 2^m - 1]$, namely

$$H(i) = \left\lfloor \frac{d(i)}{2} + \sum_{j \in J_n} d(j) \right\rfloor$$

This transformation produces an image whose grey levels have a tonal difference proportional to the number of pixels in each level. Then there is the same number of pixels in any tonal interval of suitable width.

When $2^m$ is greater than (or even equal to) the cardinal of $J_n$ (see eq. (4)), there are empty levels in the output image; more empty levels in general than the difference between $2^m$ and the cardinal of $J_n$ because, in general, the less populated initial levels group together. This used to happen when we have a film recorder to print the image.

When we display the image on the colour television screen of the RAMTEK GX 100B interactive terminal that has only 16 grey levels, this method produces a flatter histogram by accumulation of several initial levels on the same output level.

4. EXAMPLES OF RADIOMETRIC ENHANCEMENT OF LANDSAT MSS IMAGES

Let us apply the previous ideas to a practical example. We consider a subimage of a LANDSAT multispectral scanner image: the band 7 of frame 2223-10132. The subimage has 1024 pixels of width, starting in pixel 51, and 714 lines of length, starting in line 1266, and corresponds to a region of
Fig. 8. Equalizing enhancement function for the example image.
approximately 58.4 Km by 56.4 Km just south of Madrid.

We have added at the bottom left side of every image we are going to show up a grey wedge for the sake of reference. It contains 17 grey levels (namely 0, 16, 32, 48, 64, 80, 96, 112, 128, 144, 176, 192, 208, 224, 240 y 255) hence one can check the influence of development and/or printing in order to do comparisons among the pictures. The length of the grey wedge corresponds to 29 Km in the image. The images are not registered but the DIONMED D-47 film recorder is able to correct the distortion due to the rectangular shape of LANDSAT MSS image pixels.

In Fig. 1 we show the histograms \( P(i) \) of the above mentioned subimage in logarithmic scale (*) values of \( i \) greater than 63 are omitted because this band actually contains 6-bit data. Obviously it is far from a normal distribution, but seems to be more similar to a superposition of several gaussian distribution. Nevertheless, as they appear not clearly separated, the overall aspect of the histogram is quite bell-shaped at variance to Fig. 2.

In fact Fig. 2 is the histogram of an image representing a reservoir and its surroundings. It shows up two clearly separated peaks, the one at low levels corresponding to the water and the other to the dry land. This always happens when we deal with an image that includes a big area of water or snow covered (that produces a peak at the highest levels). As we pointed out in Section 3.2., we must use a piece-wise linear enhancement function (15) or the equalized function (18) if we want to see the structure in the two regions.

Let us come back to Fig. 1. The histogram has mean \( \mu = 27.07 \) and standard deviation \( \sigma = 5.08 \). Fig. 3 shows the original image enhanced using eq. (11) with \( a=4 \) and \( b=0 \). As a matter of fact such an enhancement is simply the adaption of the grey level range of the input to the grey level range of the output: ignoring the grey wedge, the output would have been the same if we had recorded the original data using the 6-bit scale of the film recorder.

The poor visual effect of Fig. 3 clearly indicates the need for a real radiometric enhancement. We will try the linear enhancement of eq. (11) with \( a \) and \( b \) given by eq. (14) using several values of \( v \). Hence

\[
a = \frac{127.5}{\nu \sigma} = \frac{25.10}{\nu}
\]  

(19a)

(*) When \( P(i) = 0 \) we plot the value 1.
Fig. 9 — Example image enhanced with the function of Fig. 8
Table 1 summarizes the parameters used to obtain Fig. 4-7. We indicate under 'left tail" the original levels that are mapped onto level 0, and under "right tail" those mapped onto 255, along with the corresponding percentages of pixels of those values.

It is apparent that \( v=4 \) produces a too poor contrast and \( v=1 \) a excessively high contrast with too many pixels accumulated in the end values. Between \( v=2 \) and \( v=3 \), may be the best value; possibly more near than \( v=2 \). This must be though of only as a hint. Every image is a particular problem whose histogram must be studied prior to any decision not only about the value of \( v \) but even about whether a linear function may be used or not.

In Fig. 9 we show the same image enhanced with the equalization function \( H \) of eq. (18) that is represented in Fig. 8. This is a good method that gives good contrast in general (the more populated the levels the more separated), does not produce an important accumulation of pixels in the end levels and can be applied to all images. Nevertheless this enhancement method is not used (except when \( m \) is smaller than \( n \), see eq. (2)): it is usually preferred the (conceptually) more simple linear enhancement.

5. COMBINATION OF SEVERAL RADIOMETRIC ENHANCEMENT FUNCTIONS

The techniques so far described are intended to improve the appearance of the whole image. It is obvious that often a smaller subimage may be better displayed using a different enhancement function, but the use of this function to enhance the whole image implies a poorer aspect of other areas.

To show this with a practical example we take a subimage of band 4 of LANDSAT frame 1028-10200. The subimage has 1050 pixels of width, starting on pixel 2171, and 900 lines of length, starting on line 1 and corresponds to an area of 59.9 Km by 71.1 Km at the NE of Zaragoza and including it. A grey wedge has been added as before.

This subimage has mean \( \mu_1=46.46 \) and standard deviation \( \sigma_1=10.69 \). Fig. 10 shows it linearly enhancement with eq. (11) being the gain \( a_1=5.96 \) and the bias \( b_1=-149.56 \). These values correspond to \( v=2 \). Levels 0 to 25, which include 0.96% of the pixels, are mapped onto level 0 and levels 70 to 127,
Fig. 11.—Zaragoza image enhanced with a function adapted to enhance Los Monegros obtained from the sub-image data with $v = 2$. 

*ORIGINAL PAGE IS OF POOR QUALITY*
Fig. 12—Zaragoza image enhanced with \( v = 2 \) (as in Fig. 10) in which Los Monegros subimage has been enhanced with a more suitable function (as in Fig. 11)
with 2.49% are mapped onto level 255.

Let us consider a subimage of the previous one with 400 pixels, starting on pixel 2361, by 100 lines, starting on line 589. It corresponds to an area of 22.8 Km by 7.9 Km on Los Monnegros, a very arid region N.E. of Zaragoza. This smaller subimage has mean $\mu_2=56.99$ and standard deviation $\sigma_2=8.80$: it is brighter than most of the bigger image and has less relevant radiometric levels. To enhance this subimage using eq. (11) and $v=2$ we take a gain $a_2=7.24$ and a bias $b_2=-285.34$. Levels 0 to 39 with 0.88% of the pixels are mapped onto 0 and levels 75 to 127 with 2.34% of the pixels are mapped onto 255.

Using the latter enhancement 27.44% of the pixels of the bigger image are assigned the value 0 and 0.66% the value 255. Hence the overall image, as shown in Fig. 11, is badly deteriorated by this enhancement that optimizes the appearance of Los Monnegros.

A solution to the problem of having a good display of a subimage being, at the same time, able to see properly its surroundings is the one shown in Fig. 12. A enhancement function with $a_2$ and $b_2$ is applied to Los Monnegros subimage while another enhancement with $a_1$ and $b_1$ is applied to the remainder of the image. The only obvious drawback is that we see a discontinuity on the border of the subimage.

6. RADIOMETRIC ENHANCEMENT OF COLOUR IMAGES

The best way to enhance a colour image is to apply one of the methods so far studied to each band separately as if they were black and white images.

This is also what we do when using the RAMTEK GX-100B display system. Nevertheless we must point out that, given that its refresh memory has only 8 bits per pixel to be distributed among the three bands we usually are compelled to take $J_3$ for two of the colours and $J_2$ for the other as the set of output grey levels instead of $J_4$ which can be used for single band images.

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DETERMINATION OF UNEORRELATED BANDS IN A LANDSAT MSS IMAGE

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1. INTRODUCTION

When we want to produce a false colour print with a LANDSAT MSS image that has four bands we must first determine which one will be excluded. The usual convention is to omit band 6. But we do not know how much information we are disregarding with that choice. On the other hand, all four bands are correlated and we are introducing some redundant information with the three bands kept.

Thus it would be desirable to have a method to extract the real information content of all bands and put it in some way in no more than three new bands (to be assigned the three fundamental colours). Automatic classifiers would also take advantage of such a method because they would avoid the expensive processing of redundant data.

The best way to solve this problems is to obtain uncorrelated bands, i.e., bands that have no correlation when we compute statistics all over the image. These bands are linear combinations of the original ones and their amounts of information decrease very rapidly from the first to the last.

In Section 2 we present the mathematical method to obtain uncorrelated bands for an image with an arbitrary number of them. It is based on the calculation of the eigenvectors of the covariance matrix. In Section 3 we discuss a practical example.

It is obvious that this method will be even more useful when we deal with
images containing more than four bands. In that case we will be interested in the three more significant bands in order to display a false colour image (even if there are more than three bands with a relevant amount of information). In automatic classification we will be able to supply the classifier with an image with nearly the same information as the original but with less bands.

2. DETERMINATION OF THE UNCORRELATED BANDS

Let us consider any pixel of a n-band multispectral image as an element \( \mathbf{x} \) of the n-dimensional vector space on the real numbers \( \mathbb{R}^n \), being the radiometric intensity levels in the n bands, \( x_i, i=1,...,n \), its n coordinates on a given orthonormal base \( \{ \mathbf{e}_i \}, i=1,...,n \). Hence, using Einstein summation convention.

\[
\mathbf{x} = \mathbf{x}_i \mathbf{e}_i
\]  

As a matter of fact pixels are very special elements because their coordinates on the base \( \{ \mathbf{e}_i \} \) are integer numbers that can be written with m binary digits, i.e.

\[
x_i \in \mathbb{J}_m = \{ a | a \in \mathbb{Z} \cap \mathbb{R}, 0 \leq a < 2^m - 1 \}
\]  

We allow during the following calculation pixel coordinates to take on real values and only in the last step of the process we will approximate them by integer numbers of m bits provided that they represent intensity levels of digital images.

Let us also consider a n-band digital image as a vectorial random variable \( \mathbf{X} \) (whose components referred to the base \( \{ \mathbf{e}_i \} \) are \( X_i, i=1,...,n \) ) on the space of events \( \mathbb{R}^n \).

The variance of \( \mathbf{X} \) is the matrix \( \mathbf{C} \) of covariance of its coordinates

\[
\mathbf{C} = \mathbf{E}(\mathbf{X} \otimes \mathbf{X}) - \mathbf{E}(\mathbf{X}) \otimes \mathbf{E}(\mathbf{X}),
\]  

where \( \mathbf{E} \) denotes expectation and \( \otimes \) the tensor product. It is a symmetric matrix so it can be diagonalized. Let us call \( \lambda_i \) its eigenvalues, i.e. the roots of the secular equation

\[
| \mathbf{C} - \lambda \mathbf{I} | = 0,
\]  

being \( \mathbf{I} \) the identity matrix, in decreasing order, i.e., \( \lambda_1 \geq \lambda_2 \geq ... \geq \lambda_n \). We assume
Fig. 2—Band B enhanced proportionally to band A
that there is no degeneracy, although this assumption is not essential to the calculation but only makes it simpler; furthermore it is true in all practical cases. Let us call \( \mathbf{f} \) the eigenvectors of \( \mathbf{C} \):
\[
\mathbf{Cf} = \lambda \mathbf{f}
\]
and \( \mathbf{F} \) the orthogonal matrix that diagonalizes \( \mathbf{C} \):
\[
\mathbf{FCF}^{-1} = \Lambda
\]

being
\[
\Lambda_{ij} = \lambda_i \delta_{ij}
\]
The columns of \( \mathbf{F} \) are the eigenvectors \( \mathbf{f} \):
\[
F_{ji} = (\mathbf{f}_i)_j
\]
The new random variables
\[
Y_i = F_{ij} X_j, \quad i=1, \ldots, n,
\]
which are the coordinates of \( \mathbf{x} \) on the base \( \{\mathbf{f}_i\} \), are then uncorrelated variables provided that their covariance matrix is \( \Lambda \). The standard deviation of the probability distribution of \( Y_i \) is then \( \sqrt{\lambda_i} \).

Only when \( \mathbf{x} \) has a normal probability distribution can we assure that \( Y_i \) are independent random variables and not simply uncorrelated.

Hence the pixel \( \mathbf{x} \) has coordinates in the base \( \{\mathbf{f}_i\} \), i.e. intensity levels in the new uncorrelated bands
\[
Y_i = F_{ij} X_j
\]
As we want pixels to take values on \( J_m \), we must approximate their values. Then we finally construct \( n \) new quasi-uncorrelated bands in which the intensity levels are
\[
z_i = \text{Int} (a Y_i + b_i)
\]
The parameters \( a \) and \( b_i \), \( i=1, \ldots, n \) are introduced to guarantee that \( z_i \in J_m \).

Taking into account that the maximum length of the interval \( y_i \) can take values on is \( (2^m - 1) \sqrt{n} \), i.e. the length of the diagonal of the \( n \)-dimensional hy-
Fig. 3—Band C enhanced proportionally to band A

Fig. 4.—Band D enhanced proportionally to band A
percube, we take

$$a = \frac{1}{\sqrt{n}}$$

(12)

to reduce to a length $2^n - 1$ the range of $z_i$. We also take

$$b_i = \frac{2^m - 1}{2} - E(Y_i) = \frac{2^m - 1}{2} - \frac{P_{ij} E(X_j)}{2}$$

(13)

to center the probability distribution of $z_i$ in the middle point of its range.

The bands thus constructed are approximately uncorrelated (although we usually refer them simply as uncorrelated bands) whose probability distributions have means and standard deviations approximately equal to $(2^m - 1)/2$ and $\sqrt{\lambda_i/n}$ respectively.

3. DISCUSSION OF A PRACTICAL EXAMPLE

We are going to apply this technique to LANDSAT MSS images, so now $n=4$ (the four bands are called 4, 5, 6 and 7) and we take $m=8$, the fact that these data have actually 7 or 6 bits being taken into account by the values of $b_i$. We will call the new quasi-uncorrelated bands, A, B, C and D.

The eigenvalues $\lambda_i$ are ordered in decreasing order so that band A has the greatest standard deviation and band D the smallest one.

As a practical example we take a subimage of frame 2223-10132 (of September the 2nd, 1975) of 1024 pixels of width, starting on pixel 51, by 715 lines of length, starting on line 551. It corresponds to an area of 58.4 Km. by 56.5 Km. around Madrid. A grey wedge with 17 levels ($16^k$, $k=0,1,...,15$ and 255) is added at the bottom of the pictures that we will show; it can be used as a reference to take into account the possible differences introduced by the development and printing processes. The length of the wedge corresponds to 29 Km on the image. We use a DICOMED D-47 film recorder to produce the photographs through its 8-bit linear scale and non square pixel compensation facilities.

Table 1 lists the means and standard deviations of the original image. The
Fig. 5.—Band B with a maximum enhancement
covariance matrix is
\[
\begin{pmatrix}
59.88 & 106.51 & 84.00 & 28.60 \\
106.51 & 201.11 & 157.82 & 54.50 \\
84.00 & 157.82 & 150.02 & 58.08 \\
28.60 & 54.50 & 58.08 & 25.59
\end{pmatrix}
\] (14)

and the correlation matrix, defined by
\[
\rho_{ij} = \frac{C_{ij}}{\sqrt{C_{ii}C_{jj}}}
\] (15)
is:
\[
\begin{pmatrix}
1.000 & 0.971 & 0.886 & 0.731 \\
0.971 & 1.000 & 0.909 & 0.760 \\
0.886 & 0.909 & 1.000 & 0.937 \\
0.731 & 0.760 & 0.937 & 1.000
\end{pmatrix}
\] (16)

Table 2 indicates the eigenvalues of C that correspond to the new bands A, B, C and D, the actual standard deviation of these bands (the differences between these values and \(\sqrt{\lambda_i}/2\) being produced by the round-off error) and the values of the transformation coefficients.

**TABLE I**

<table>
<thead>
<tr>
<th>Band</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>29.03</td>
<td>7.74</td>
</tr>
<tr>
<td>5</td>
<td>41.28</td>
<td>14.18</td>
</tr>
<tr>
<td>6</td>
<td>50.87</td>
<td>12.25</td>
</tr>
<tr>
<td>7</td>
<td>22.43</td>
<td>5.06</td>
</tr>
</tbody>
</table>

With this examples we realize a very general fact: there is a high correlation between the two visible bands and between the two infrared bands, while the correlation between a band of the first pair and a band of the last pair is smaller although rather big.
<table>
<thead>
<tr>
<th>Band</th>
<th>$\lambda_i$</th>
<th>Standard deviation</th>
<th>Projection over bands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>A</td>
<td>409.36</td>
<td>10.12</td>
<td>0.368</td>
</tr>
<tr>
<td>B</td>
<td>23.27</td>
<td>2.43</td>
<td>-0.314</td>
</tr>
<tr>
<td>C</td>
<td>2.69</td>
<td>0.85</td>
<td>0.859</td>
</tr>
<tr>
<td>D</td>
<td>1.27</td>
<td>0.62</td>
<td>0.169</td>
</tr>
</tbody>
</table>

**TABLE 2**

Uncorrelated band image
Bands C and D of the new image have very small information contents, most of the information of the original image having been accumulated in bands A and B.

Provided that even the standard deviation of band A is small we must radiometrically enhance the images before showing them to a photointerpreter. Of course this step must be omitted when we want the image for an automatic classifier. In the latter case we should give to it bands A and B only because bands C and D do not add relevant information.

We apply to band A a linear enhancement such that the central peak of its distribution of semϊwidth equal to two standard deviations is assigned the whole range of output levels [0,255], being its mean at the middle point approximately. Fig. 1 shows band A so enhanced with a gain factor of 6.30.

We show in Figs. 2-4 bands B, C and D respectively enhanced with the same gain 6.30 and appropriate bias factors so that we can realize the relative amount of information of each band.

In order to know with more detail how bands B, C and D look like, we show in Figs. 5-7 these bands linearly enhanced in such a way that their distribution's central peak of semϊwidth equal to two standard deviations are assigned the whole range [0,255]. The gain factors applied are respectively 26.23, 75.00 and 102.82.

It is apparent that bands C and D contain nearly only noise. The noise sources in LANDSAT MSS images are mainly two: i) the round-off error produced in the quantization of the(analog) original signal and ii) the differences in calibration among the six sensors of each band. The former is approximately white noise and amounts at most to one radiometric level. The latter produces the typical stripping evident in many images which can amount to several levels. Both noise components are evident in bands C and D although stripping obviously dominates. The underlying signal in band C (see Fig. 6 in which this band is enhanced as much as possible) shows mainly structural features as reservoir limits, roads and rivers or more properly the vegetation besides them (remember that the image corresponds to summer time). The underlying signal of band D hardly shows some uniform bodies as the city,
Fig 7 — Band D with a maximum enhancement
reservoirs or forests (see Fig. 7).

We have anticipated that because of the high degree of correlation among the four bands of LANDSAT MSS image (see eq. (16)) we really have not four bands with information. In fact we have two bands with relevant information, namely bands A and B (see Figs. 1 to 4).

Comparing bands A and B (see Fig. 5 in which band B is more enhanced) we realize that one complements in some way the other so that both together have nearly all the information existing in the four original bands. Band A contains a lot of information concerning both structural features (as rivers and roads) and different land areas (urban, forests, water, etc.). Band B makes more emphasis on structural features (the dendritic aspect of Guadarrama river network is clearly visible).

Hence bands A and B alone may be used to produce false colour images (see Fig. 8) or to perform automatic classification. In fact Fig. 8 is a composite of band A (enhanced as in Fig. 1) in green and band B with a maximum enhancement (as in Fig. 5) in red. Note that the name of each band appears in the complementary colour of that in which it is recorded and the bottom wedge is obviously yellow. Despite its unusual aspect, this picture may be really valuable for photointerpretation. This colour assignment has been selected in order for vegetation to appear red (as is usual in LANDSAT false colour images).

Finally in order to clearly understand the real meaning of the uncorrelated bands A, B, C and D we consider the four dimensional histogram \( P(x) \), \( x \in \mathbb{R}^4 \), is the number of pixels with intensity levels \( x_1 \) in band 4, \( x_2 \) in band 5, \( x_3 \) in band 6 and \( x_4 \) in band 7. Thinking of it as a mass distribution in the four dimensional euclidean space we realize that it is very flat along the directions \( \hat{e}_4 \) (that corresponds to band D) and \( \hat{e}_3 \) (corresponding to band C). Hence it is quite a two dimensional "object" longer along direction \( \hat{e}_1 \) (band A) than along \( \hat{e}_2 \) (band B).
Fig. 8.—Two colour composite of band A (green) and band B with maximum enhancement (red).
ACKNOWLEDGEMENTS

I acknowledge J. González of Centro de Investigación UAM-IBM for the preparation of a preliminary version of the computer program to obtain uncorrelated images and G. López de Lemos for the recording and development of photographs.

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THE BAND RATIOING TECHNIQUE APPLIED TO LANDSAT MSS IMAGES

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1. INTRODUCTION

Band ratioing is becoming one of the best known digital techniques to obtain new bands with relevant information from a multispectral image. The reason is the following: Being the light intensity measured in each band by a multispectral device (a multispectral scanner for instance) approximately the product of the light intensity impinging the viewed object by its reflectivity, the quotient of the measures in two bands is expected to be independent of the illumination.

This technique turns out to be very useful to enhance certain features in LANDSAT MSS images. It has been used to eliminate light cloud coverage 1) and in geological applications 2)3) with relative success. On the other hand this process is very sensitive to noise, specially to the typical stripping (see Section 3 below).

In Section 2 we present three formulae to obtain quotient images. The first one (see Section 2.1) gives good displays in systems with few grey levels (as television screens for instance) but is not suited to film recorders if we do not perform an equalizing enhancement 4) prior to recording. The other two formulae (see Sections 2.2 and 2.3) perform an enhancement at the same time that they compute the ratio. The last one of them (Section 2.3) uses the logarithm of the quotient in order to transform multiplications and divisions into additions and subtractions thus yielding a symmetric distribution.
In Section 4 we apply the methods described in Sections 2.2 and 2.3 to a particular example aimed to show up the gallery vegetation beside narrow rivers.

2. IMAGE RATIOING METHODS

Let us call $x$ and $y$ the radiometric level of a pixel in the two bands that participate in the ratio and $z$ the resulting level of the pixel in the new quotient band. We assume that $0 \leq x, y, z \leq 255$ for the sake of generality although LANDSAT MSS image data actually contain 7 bit in bands 4, 5 and 6 and 6 bit in band 7.

2.1. The nonparametric formula of ERMAN II

The earth resources management interactive program ERMAN II performs ratios of LANDSAT MSS images. The output image contains the four original bands plus the twelve possible ratios. The formula used is

$$
\begin{align*}
  z &= \begin{cases} 
  \text{Int}\left(\frac{x}{y+1}\right) & \text{if } \frac{x}{y+1} \leq 255 \\
  255 & \text{if } \frac{x}{y+1} \geq 255
  \end{cases} 
\end{align*}
$$

where Int stands for integer value.

The addition of a unit to the denominator prevents it from vanishing. $i$ and $j$ denote the numerator and denominator bands and the constant $K_{ij}$ has the values $K_{45} = K_{46} = K_{54} = K_{56} = K_{64} = K_{65} = 32$, $K_{47} = K_{57} = K_{67} = 16$, $K_{74} = K_{75} = K_{76} = 64$.

Hence $z = 32$ when both bands have the same radionetric level (thinking of band 7 as multiplied by 2 in order for all bands to have the same range of levels). There is an obvious lack of symmetry because 32 levels are assigned to the case in which $x \leq y$ and 224 to that in which $x > y$ and half the output pixels take value on a number of levels of the order of 32 (sometimes even much less) while the other half take values on much more levels. The distribution of pixels is
very concentrated on rather low levels and the contrast of the picture
that we can produce with a linear scale film recorder will be very poor.
But the application of a radiometric enhancement to the quotient using
an equalizing function \(^1\) overcomes this drawback. As a matter of fact
this is the way in which ERMAN II operates: the transformation of levels
is such that in each one of the 16 levels available in black and white
(or the 8 or 4 levels available in false colour) using the RAMTEK GX-100 B
interactive display units, it tends to be approximately the same number
of pixels.

2.2. Parametric ratioing formula

When we are going to display the quotient image by means of a film
recorder with 8-bit linear scale we must radiometrically enhance the
data. This enhancement may be done at the same time that we calculate
the ratio simply through the use of suitable parameters.

Let us define the quotient by

\[
z = \begin{cases} 
0 & \text{if } 0 \geq \frac{x+1}{y+1} + b \\
\text{Int} \left( a \frac{x+1}{y+1} + b \right) & \text{if } 0 \leq \frac{x+1}{y+1} + b \leq 255 \\
255 & \text{if } 255 \geq a \frac{x+1}{y+1} + b
\end{cases} \tag{2}
\]

The addition of 1 to the numerator is a simple matter of symmetry.
The parameters \(a\) and \(b\) control the contrast and brightness of the
output image and, at the same time, the range of values of \((x+1)/(y+1)\)
that are assigned the whole interval \([0, 255]\) excluding the tail
cut-offs.

To determine \(a\) and \(b\) we can follow many criteria but in general the
more useful are the following:
Fig. 1.—Quotient image SD7 obtained with $c = 1.5$
i) Take $1/c$ and $c$ as cut-off points. Hence the quotient values

$$\frac{1}{c} \leq \frac{x+1}{y+1} \leq c$$  \hspace{1cm} (3)

are assigned the whole range of levels while smaller values are assigned 0 and bigger values 255. Then

$$a = \frac{255\ c}{c^2 - 1} \hspace{1cm} b = -\frac{255}{c^2 - 1}$$  \hspace{1cm} (4)

and the value

$$\text{Int}\left(\frac{255}{c+1}\right)$$  \hspace{1cm} (5)

is assigned when $x\approx y$. It remains to determine the parameter $c$ that limits the ratio values allowed. Obviously we can determine a good value of $c$ if we know beforehand the distribution of quotients otherwise $c$ must be estimated by trial and error.

ii) Take the cut-off points at $z/c$ and $z$ c being

$$z = \frac{x+1}{y+1}$$  \hspace{1cm} (6)

and $\bar{x}$ and $\bar{y}$ are the mean values of the numerator and denominator bands. Hence the whole range of output levels is assigned to

$$\frac{z}{c} \leq \frac{x+1}{y+1} \leq z \ c$$  \hspace{1cm} (7)

and

$$a = \frac{255\ c}{z\ (c^2 -1)} \hspace{1cm} b = -\frac{255}{c^2 -1}$$  \hspace{1cm} (8)

and the value of eq. (5) is assigned to $z$. The determination of $c$ rises the same problems as before.
The second method has an obvious advantage with respect to the other one. Even though \( z \) is not the mean value of the quotient, it is in general a good estimate of it, actually the only one we have before calculating the quotient image. Therefore this method assigns the whole range of levels to a (logarithmically) symmetric interval around a point near to the actual mean.

2.3. Logarithmic ratioing formula

Images obtained by means of the parametric ratioing formula with a (logarithmically) symmetric interval are usually dark: their means are smaller than 127.5. The lack of linearity that implies that fact desappears when we use a logarithmic scale to record the image.

If instead we use directly a logarithmic ratioing formula as eq. (9) below and record images using a linear scale we have more flexibility and keep full control of the calculation. Furthermore the computation time may be reduced by the use of a look-up table with the logarithms of the integer numbers from 1 to 256.

Thus we define the logarithmic quotient image whose pixels have intensity levels given by

\[
z' = \begin{cases} 
0 & \text{if } 0 \leq \alpha \log\left(\frac{x+1}{y+1}\right)+\beta \\
\text{Int} \left[\alpha \log\left(\frac{x+1}{y+1}\right)+\beta\right] & \text{if } 0 \leq \alpha \log\left(\frac{x+1}{y+1}\right)+\beta < 255 \\
255 & \text{if } 255 \leq \alpha \log\left(\frac{x+1}{y+1}\right)+\beta 
\end{cases} \tag{9}
\]

Where \( \log \) stands for logarithm of base 2.

To determine \( \alpha \) and \( \beta \) we can follow many criteria but we point out again the two more useful:
Fig. 2.—Quotient image 7DS obtained with c = 1.5
i) Take $1/c$ and $c$ as cut-off points i.e.

$$-\log c \leq \log \frac{x+1}{y+1} \leq \log c \quad (10)$$

We must assign the intensity 127.5 when $x=y$ and

$$a = \frac{127.5}{\log c}, \quad \beta = 127.5 \quad (11)$$

ii) Take $\overline{z}/c$ and $\overline{z}c$ as cut-off points (see eq.(6)). Then

$$\log \overline{z} - \log c \leq \log \frac{x+1}{y+1} \geq \log \overline{z} + \log c \quad (12)$$

We want to assign the intensity 127.5 when $\frac{x+1}{y+1}=\overline{z}$ hence

$$a = \frac{127.5}{\log c}, \quad \beta = 127.5(1-\frac{\log \overline{z}}{\log c}) \quad (13)$$

Notice that the use of the logarithm of the quotient implies a complete symmetry between the cases $x>y$ and $x<y$ and therefore the mean of the distribution of $z'$ is higher than the mean of $z$.

3. THE EFFECT OF NOISE IN QUOTIENT IMAGES

Quotient images are very sensitive to noise. To see it let us consider eq.(2) in the simplified non-integer form.

$$z = a \frac{x+1}{y+1} + b \quad (14)$$

We do not take into account the round-off error noise introduced by the ratioing method but only the noise already existing in the original images. As we are mainly concerned with LANDSAT MSS images the dominant noise is the well known stripping introduced by the differences in calibration among the six sensors of each band, that can amount to several grey level units.
Fig. 3.—Quotient image LSD7 obtained with c = 1.5
Imagine that the values of a pixel in the two bands to be divided are

\[ x = x_0 + \varepsilon \]
\[ y = y_0 + \delta \]

(15)

being \( x_0 \) and \( y_0 \) the values that correspond to the pure signal, \( \varepsilon \) and \( \delta \) the noise components and

\[ z_0 = \frac{x_0 + 1}{y_0 + 1} \]

(16)

The noise component of the output image is

\[ n(\varepsilon, \delta) = a \left( \frac{x_0 + 1 + \varepsilon}{y_0 + 1 + \delta} - \frac{x_0 + 1}{y_0 + 1} \right) \]

(17)

defined as a function of the input noise components \( \varepsilon \) and \( \delta \). It obviously increases with the gain factor \( a \).

The noise in the quotient image induced by noise in the numerator image is

\[ n(\varepsilon, 0) = a \frac{\varepsilon}{y_0 + 1} \]

(18)

that is independent of the pixel's grey level of the numerator image and increases when the denominator decreases. Then it is more apparent in the brighter areas of the quotient image. The noise caused by noise in the denominator image is (*)

\[ n(0, \delta) = a \frac{\delta}{y_0 + 1} \]

(19)

that increases as the numerator image becomes brighter and the denominator one becomes darker.

The same conclusions may be drawn from the logarithmic formula (9) although calculations are more involved.

(*) Remember that \( y_0 + 1 + \delta = y + 1 \leq 1 \) and the denominator never vanishes.
Fig. 4 — Quotient image L7DS obtained with $c = 1.5$
As a matter of fact the stripping in water areas may be enormous, completely masking out any other information. Because of this important drawback, the ratio of two images with considerable amounts of noise may be a useless image for nearly all purposes. Therefore this technique must be applied with care, making a previous selection of suitable images.

4. APPLICATION TO A PARTICULAR EXAMPLE

We take a subimage of LANDSAT MSS frame 2223-10132 in order to apply the parametric ratioing methods discussed in Sections 2.2 and 2.3. This subimage has 1024 pixels of width, starting on pixel 1057, by 714 lines of length, starting on line 1266. It was taken on summer time (September the 2nd, 1975).

This image corresponds to an area of 58.4 km by 56.4 km around Tajo river, East of Aranjuez, between its tributaries Tajuña (top) and Cedron (bottom). This area is rather arid and with scarce vegetation during the summer, the rivers being too narrow to be directly seen in LANDSAT imagery.

We are going to take bands 5 and 7 and calculate both quotient images, namely 5/7 and 7/5. This is a good method to detect rivers in conditions similar to those of the considered area. Actually what we visualize is no the water but the gallery vegetation beside the rivers that ranges from wide irrigation areas in the main rivers to two rows of trees in the smaller tributary rivers.

To begin with we study both bands separately and realize that they are good images in the sense that their signal to noise ratios are high. We list in Table 1 their means and standard deviations.
Fig 5 — Quotient image 7D5 obtained with c = 5.0
Table 1

<table>
<thead>
<tr>
<th>Original Bands</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>57.26</td>
<td>12.81</td>
</tr>
<tr>
<td>7</td>
<td>28.39</td>
<td>5.28</td>
</tr>
</tbody>
</table>

We compute the value of $\tilde{z}$ (see eq.(6)) for the quotient of bands 5/7 being $\tilde{z} = 1.98$, and for the quotient of bands 7/5 where $\tilde{z} = 0.50$.

Now we can obtain the quotients using criterion ii) (see Sections 2.2 and 2.3 above) to determine $a$ (or $c$) and $b$ (or $b$). We will try three values of $c$, namely $c = 1.5, 2.0$ and $3.0$.

Table 2 summarizes all data about these quotient images. In the first column we indicate the kind of quotient image. 5D7 and 7D5 are the quotients 5/7 and 7/5 respectively computed through the formula of eq.(2) with $a$ and $b$ given by eq.(8). L5D7 and L7D5 indicate the same quotients as before but computed through the logarithmic formula of eq.(9) with $a$ and $\beta$ given by eq.(13). The second column indicates the value $c$ used. The third and fourth columns give respectively the values of $a$ and $b$ for images obtained using eq.(2) and give the values of $a$ and $\beta$ when the quotient image have been got by using eq.(9). The fifth and sixth columns give the means and standard deviations of the quotient images. The seventh and eighth columns give the percentages of pixels that are accumulated on the end point levels 0 and 255, i.e. the percentages of pixels that do not satisfy respectively the first or second inequalities of eq.(7) (in case of 5D7 and 7D5 images) or eq.(12) (in case of L5D7 and L7D5 images). Finally the last column indicates which one of the figures show the image (note that not all of them are shown).

The first fact that we observe is that the greater is $c$ (i.e. the wider is the range of quotient values allowed the greater is the gain factor $a$ or $c$ and hence the greater are the standard deviation and the contrast
<table>
<thead>
<tr>
<th>Quotient Band</th>
<th>Parameter Values Used</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Pixels at end levels</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C  a / d  b / β</td>
<td></td>
<td></td>
<td>% at 0  % at 255</td>
<td></td>
</tr>
<tr>
<td>5D7</td>
<td>1.5, 154.55, -204.00</td>
<td>102.87</td>
<td>23.16</td>
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<tr>
<td>5D7</td>
<td>2.0, 85.85, -85.00</td>
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<tr>
<td>5D7</td>
<td>3.0, 48.70, -31.88</td>
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<td>11.69</td>
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<td>7D5</td>
<td>1.5, 612.00, -204.00</td>
<td>107.40</td>
<td>38.89</td>
<td>0.02  2.27</td>
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<tr>
<td>7D5</td>
<td>2.0, 340.00, -85.00</td>
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<td>27.49</td>
<td>0.00  0.91</td>
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</tr>
<tr>
<td>7D5</td>
<td>3.0, 191.25, -31.88</td>
<td>66.15</td>
<td>18.66</td>
<td>0.00  0.15</td>
<td>5</td>
</tr>
<tr>
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<td>126.88</td>
<td>36.40</td>
<td>2.21  0.02</td>
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</tr>
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<td>24.48</td>
<td>0.86  0.00</td>
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<td>16.72</td>
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<td>6</td>
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<tr>
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<td>36.40</td>
<td>0.02  2.21</td>
<td>4</td>
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<td>16.72</td>
<td>0.00  0.15</td>
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</table>

**TABLE 2**
of the quotient image. Consequently the percentage of pixels accumulated on the end values decreases as \( c \) increases.

The means of the quotient images \( 5D7 \) and \( 7D5 \) decrease and then the images became darker as \( c \) increases (see eq.(5)). The differences between these means and the value \( 255/(c+1) \) (namely 102.20 when \( c=1.5 \), 85.00 when \( c=2.0 \) and 63.75 when \( c=3.0 \)) are mostly due to the fact that \( \tilde{z} \) is not the mean of \( (x+1)/(y+1) \), and can be thought of as an estimate of the amount by which \( \tilde{z} \) differs from the actual mean. The same can be said of the differences between the means of images \( L5D7 \) and \( L7D5 \) and 127.5. We realize that all those differences are small and then our guess of estimating the quotient mean by \( \tilde{z} \) turns out to be completely justified.

To understand the very high values of the gain \( a \) in \( 7D5 \) images, remember that \( \tilde{z} = 0.50 \) for this quotient while \( \tilde{z} = 1.98 \) for the \( 5D7 \) images whose gain factors are obviously much smaller. (see eq.(8)). In the \( L5D7 \) and \( L7D5 \) images this fact is accounted for by the bias \( \beta \) much higher in \( L7D5 \) than in \( L5D7 \) (see eq.(13)).

The images \( L5D7 \) and \( L7D5 \) obtained with the same \( c \) are positive-negative pairs. In fact, their intensity levels are related by (see eq.(9)).

\[
\tilde{z}'(L7D5) = 255 - \tilde{z}'(L5D7)
\] (19)

On the other hand, image \( 7D5 \) is no longer the negative of image \( 5D7 \) for the lack of symmetry already discussed (see eq.(2)).

To obtain the photographs for display we use the DICOMED D-47 film recorder with its 8-bit linear scale and non-square pixel compensation facilities. We also add at the bottom right side of our photographic displays, a grey wedge in order for the reader to be able to account for the possible printing deficiencies. Its 17 levels are \( 16^k \), \( k=0,1,\ldots,15 \) and 255. The length of this wedge corresponds to 29 km on the image.
Fig. 6.—Quotient image LSD7 obtained with $c = 3.0$
Looking at Fig. 1-6 we realize the absence of relevant stripping as was expected from the quality of the originals. These images clearly show up the vegetation near the rivers, although other kind of information is not very apparent in part because of the homogeneity of the depicted area.

Let us compare Fig. 2 with Fig. 5 that are 7D5 images obtained with different values of c. Fig. 1, with a smaller value of c, has higher contrast and contains more information about the irrigation areas near the main rivers. It also shows more clearly the narrower rivers and gives some information about structures on the more homogeneous region between the rivers. The same conclusions are drawn from a comparison between the two L5D7 images of Fig. 3 and Fig. 6.

Nevertheless c may not be decreased to much because it induces an accumulation of pixels on the levels 0 and 255 than, when it becomes too big, reduces the actual information content of the image.

The comparison between Fig. 3 and Fig. 4, that are negative of each other, confirms that they have the same information.

Images 5D7 and 7D5 on the other hand (see Fig. 1 and 2) do not have the same information. The brighter parts of each one have more information than their (darker) counterparts of the other. This owe to the fact that a certain interval of quotient values greater than one is assigned more levels than the interval subtended by its (smaller than one) inverses. Hence there is more information about the neighbourhood of the rivers in 7D5 than in 5D7.

The brighter parts of images 5D7 and 7D5 also have more information than those of images L5D7 and L7D5 respectively. Nevertheless the latter images have more overall information than the former (compare Figure 1 with Fig. 3 and Fig. 2 with Fig. 4).
Our final conclusion is that image ratioing, using suitable parametric formulae to perform a radiometric enhancement at the same time, is a good tool to emphasize certain special features in LANDSAT MSS images though it must be used with care because of its noise sensitivity. The bands to be divided and the particular formula to be used are to be selected ad hoc, while the determination of parameter values rests a trial and error question.

ACKNOWLEDGEMENT

I acknowledge L. Montoto of Centro de Investigación UAM-IBM for his suggestion of using the quotients of bands 5 and 7 as an example of our image ratioing methods, pointing out that this is the best way to show up the gallery vegetation that signals the presence of narrow rivers in Central Spain. I also acknowledge G. López de Lemos of Instituto Geográfico y Catastral for the recording and development of photographs.

REFERENCES


4) A. Santisteban, "Study of Radiometric Enhancement Methods Applied to LANDSAT MSS Images" on this report.

EDAPHOLOGY

MADRID AND ITS ENVIRONMENT: LAND USE AND SOILS BY DIGITAL ANALYSIS OF LANDSAT DATA.

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EDAPHOLOGY

MADRID AND ITS ENVIRONMENT: LAND USE AND SOILS BY DIGITAL ANALYSIS OF LANDSAT DATA.

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Madrid.

ABSTRACT

Digital analysis of LANDSAT data, when applied to the spectral study of Madrid and its environment by means of LARSYS program, developed at LARS/Purdue University, allows knowledge of urban structure, models, typical mediterranean mountains and main types of soils by computer classification.

The principal stages of this working program include grouping of spectral classes of land use and soils by clustering techniques.

Results obtained show that this line of investigation is promising for automatic classification of LANDSAT data applied to thematic cartography and soils identification.

1. INTRODUCTION

Digital analysis of LANDSAT-2 data taken over Madrid and its environment, using LARSYS program, is the main objective of this work, with special emphasis given to land use and soil classification.

This geographic area is selected because it presents models of varied urban structure, typical mediterranean vegetation.
of Quercus ilex and, also, because the city is settled on a geo-edaphic unit known as "Facies Madrid"; of great interest and importance from an edaphologic point of view.

The main objective was classifying the spectral classes identified, taking into consideration the following points:

- main spectral classes (urban, rural, mountain)
- urban subclasses (vegetation, hydric, edaphic)
- inventory of the area
- thematic cartography by digital techniques
- applications

2. MATERIAL AND METHODS

LANDSAT image used for automatic classification was E-2187-10143, dated July 28th, 1975, taken at 9 h. 14 m. (local time). Each band included 7,619,040 pixels, from which a subscene geometrically corrected was generated taking lines 779 to 1659 and columns 337 to 1893. Output product was a registered tape of 710 lines x 1212 columns, which provided the basic data dealing with in this report (Fig.1)

As reference material were used:

- Topographic Maps of Instituto Geográfico y Catastral at scale 1:50.000 and Servicio Geográfico del Ejército at scale 1:25.000
- Charts of Madrid streets updated
- Soil map of Spain at scale 1:1,000,000
- Aerial images at scale 1:15,000.

The methodology used on this work was operational at the Laboratory for Application of Remote Sensing-LARS/Purdue University, where LARSYS program version 3 was available.
Fig 1.—Area of study: aMadrid and its environments. Date July 28, 1975
3. ANALYSIS AND STAGES

3.1. Identification of areas and points of interest

The first problem appearing to the investigator is identifying the area to be selected for digital classification, recognizing on it the most interesting points as reference. There are two solutions in this stage.

a) Obtaining the PICTUREPRINT function in paper print with alphanumeric characters, representing 16 gray levels of intensity (reflectivity) values. It was selected band 5 (0.6 - 0.7 μ) for the purpose of easily recognizing the communication network around Madrid; but because the date of observation (July 28th), no contrast appeared with soils and other types of vegetative cover. Band 6 showed the same difficulty and the second solution, consisting in an image display, was adopted.

b) IMAGEDISPLAY function, generated in television terminal. This function allowed identification of significative points as reference of the area under study.

3.2. Selection of test sites

Four different areas were selected as test sites for basic model of calculation and classification, being the results extrapolated to the area under study. LARSYS program evaluates every point and assigns it to the most similar class.

Two areas called Retiro and Plaza de Castilla represent urban structures. The area of Casa de Campo was selected for knowing types of vegetation, water, urban classes and types of soils. The area of El Pardo represents mountain, water and soils.

Retiro and Casa de Campo test sites have 3,000 pixels, or 50 lines x 60 columns. In Plaza de Castilla 2,000 pixels
were taken (40 lines x 50 columns), and the area of El Pardo contained 4,800 pixels (80 lines x 60 columns).

3.3. Cluster of the selected areas

The spectral classes grouped in natural form were obtained for each of the test sites by means of the CLUSTER function, taking the decision of classifying with 12 classes. In the same CLUSTER function is obtained for each class the value of the mean vector and covariance matrix; which means a number of absolute value representing the average of the mean vectors correspondent to the total of class points, and a measure of dispersion of data.

Tables no. 1, 2, 3 and 4 indicate absolute values of spectral characteristics more relevant for each test site.

3.4. Separability between classes and cluster

In the function SEPARABILITY, the mean taken as reference by LARSYS, based in the values of mean vector and covariance matrix, is known as transformed divergence and its value is comprised between 0 and 2.000 (perfect separability).

The twelve classes of cluster of Retiro are grouped considering a maximum value of divergence equal to 1.700; however some classes with minor divergence were rejected because their different spectral characteristics (Figures 2 and 3).

In Plaza de Castilla, also urban area, the maximum value of divergence was limited to 1.600, combining the classes with those clusters of minor divergence than the above mentioned.

In the test site of El Pardo, divergence taken as limit was 1.500, also with the influence of the investigator as, for example, classes 1 and 2, with divergence higher than 1.650 but combined because their similar spectral responses.
\textbf{FIG. 3: MADRID AND ITS ENVIRONMENT: CLUSTER}
FIG. 2: MADRID AND ITS ENVIRONMENT: CLUSTER
### Table 1: Cluster: Madrid, Retiro

<table>
<thead>
<tr>
<th>Classes</th>
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<th>Band 7</th>
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### Table 2: Cluster: Madrid, Plaza de Castilla

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### TABLE 3: CLUSTER: MADRID, RETIRO

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### TABLE 4: CLUSTER: MADRID, CASA DE CAMPO

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<td>4 NEW BUILDINGS</td>
<td>34.68</td>
<td>46.68</td>
<td>52.04</td>
</tr>
<tr>
<td>5 CLD BUILDINGS</td>
<td>33.15</td>
<td>45.68</td>
<td>59.04</td>
</tr>
<tr>
<td>6 HAPLOXERALFS</td>
<td>30.31</td>
<td>40.26</td>
<td>54.56</td>
</tr>
<tr>
<td>7 PARKS</td>
<td>25.60</td>
<td>30.10</td>
<td>54.42</td>
</tr>
<tr>
<td>8 RESIDENTIAL</td>
<td>28.12</td>
<td>36.68</td>
<td>48.69</td>
</tr>
<tr>
<td>9 NEW BUILDINGS</td>
<td>29.06</td>
<td>37.66</td>
<td>41.77</td>
</tr>
<tr>
<td>10 RESIDENTIAL</td>
<td>25.13</td>
<td>30.14</td>
<td>43.17</td>
</tr>
<tr>
<td>11 PARKS</td>
<td>22.20</td>
<td>24.11</td>
<td>47.70</td>
</tr>
<tr>
<td>12 WATER</td>
<td>23.64</td>
<td>26.18</td>
<td>33.95</td>
</tr>
</tbody>
</table>

Vis/IR values are shown for each band.
The fourth test site, located in Casa de Campo, had a limit divergence of 1.700. As final stage every class was correlated to existing cartographic information and aerial imagery for the purpose of identification.

3.5. Individual classification of the areas

Following the methodology of LARS, after combining similar classes and identifying types of surface cover, a classification of the areas has to be done. Function MERGESTATISTICS can help in the combination of cluster classes, obtaining a new packet of cards used as input of the classification (Figures 4 and 5).

The classification is done by LARSYS program based on a maximum likelihood rule, comparing each data to all the classes and evaluating the minimum probability of error.

If after finished the individual classification, results do not agree with the objectives, it can be reviewed any phase of the analysis for correction. This happened in the area of Retiro, where a second classification was done until considered acceptable. Results obtained by means of function PRINTRESULTS are shown in tables no. 5, 6, 7 and 8.

3.6. Final classification

Once all the test sites have been classified, it is possible to obtain new absolute values of divergence in the final classes (in this case 16), for knowledge of their separability. If such problem does not appear, all the area under study can be classified with the final number of classes by the function CLASSIFYPOINTS, taking as basic data each class defined in the test sites.

Results of the final classification by PRINTRESULTS function give an idea of the spectral characteristics of the 16 classes used.
FIG. 4: MADRID AND ITS ENVIRONMENT: CLASSIFICATION
FIG. 6: MADRID AND ITS ENVIRONMENT: CLASSIFICATION
### TABLE 5: CLASSIFICATION: MADRID, RETIRO

<table>
<thead>
<tr>
<th>Classes</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>% Occupied Per Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>48.31%</td>
<td>66.38%</td>
<td>71.31%</td>
<td>28.38%</td>
<td>0.5</td>
</tr>
<tr>
<td>No Building</td>
<td>38.10%</td>
<td>51.81%</td>
<td>57.82%</td>
<td>22.07%</td>
<td>3.0</td>
</tr>
<tr>
<td>New Building</td>
<td>31.77%</td>
<td>42.12%</td>
<td>45.53%</td>
<td>17.47%</td>
<td>22.0</td>
</tr>
<tr>
<td>Compact Veget.</td>
<td>28.89%</td>
<td>34.95%</td>
<td>55.00%</td>
<td>25.64%</td>
<td>2.9</td>
</tr>
<tr>
<td>Grass</td>
<td>26.65%</td>
<td>31.97%</td>
<td>42.57%</td>
<td>18.09%</td>
<td>7.2</td>
</tr>
<tr>
<td>Old Buildings</td>
<td>28.03%</td>
<td>37.33%</td>
<td>38.74%</td>
<td>14.49%</td>
<td>37.9</td>
</tr>
<tr>
<td>Water/Streets</td>
<td>25.57%</td>
<td>31.47%</td>
<td>34.04%</td>
<td>12.69%</td>
<td>16.6</td>
</tr>
<tr>
<td>Parks</td>
<td>21.96%</td>
<td>23.53%</td>
<td>44.69%</td>
<td>21.75%</td>
<td>9.8</td>
</tr>
</tbody>
</table>

### TABLE 6: CLASSIFICATION: MADRID, PLAZA DE CASTILLA

<table>
<thead>
<tr>
<th>Classes</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>% Occupied Per Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>51.39%</td>
<td>73.81%</td>
<td>76.97%</td>
<td>30.58%</td>
<td>1.6</td>
</tr>
<tr>
<td>Squares/Parking</td>
<td>43.64%</td>
<td>63.53%</td>
<td>67.17%</td>
<td>27.05%</td>
<td>4.9</td>
</tr>
<tr>
<td>URBAN/TREES</td>
<td>33.44%</td>
<td>44.64%</td>
<td>57.70%</td>
<td>24.55%</td>
<td>9.7</td>
</tr>
<tr>
<td>NO BUILDINGS</td>
<td>39.45%</td>
<td>56.73%</td>
<td>59.73%</td>
<td>23.58%</td>
<td>10.0</td>
</tr>
<tr>
<td>Old Buildings</td>
<td>34.74%</td>
<td>47.58%</td>
<td>51.06%</td>
<td>19.75%</td>
<td>35.0</td>
</tr>
<tr>
<td>Residential</td>
<td>28.80%</td>
<td>36.64%</td>
<td>47.78%</td>
<td>20.51%</td>
<td>15.6</td>
</tr>
<tr>
<td>NEW BUILDINGS</td>
<td>29.73%</td>
<td>38.38%</td>
<td>41.35%</td>
<td>15.91%</td>
<td>22.8</td>
</tr>
</tbody>
</table>
### Table 7: Classification: Madrid, El Pardo

<table>
<thead>
<tr>
<th>Classes</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Soil</td>
<td>42,50</td>
<td>64,65</td>
<td>72,16</td>
<td>31,51</td>
<td>6,5</td>
</tr>
<tr>
<td></td>
<td>-11,97</td>
<td>-25,70</td>
<td>-27,66</td>
<td>-5,10</td>
<td></td>
</tr>
<tr>
<td>Compact Veget.</td>
<td>29,39</td>
<td>39,21</td>
<td>63,98</td>
<td>32,00</td>
<td>3,3</td>
</tr>
<tr>
<td></td>
<td>-5,21</td>
<td>-19,24</td>
<td>-16,09</td>
<td>-8,72</td>
<td></td>
</tr>
<tr>
<td>Xerochrepts</td>
<td>36,98</td>
<td>53,89</td>
<td>62,87</td>
<td>28,18</td>
<td>8,7</td>
</tr>
<tr>
<td></td>
<td>-2,86</td>
<td>-6,87</td>
<td>-7,13</td>
<td>-2,78</td>
<td></td>
</tr>
<tr>
<td>Haploxerals</td>
<td>31,67</td>
<td>45,23</td>
<td>55,69</td>
<td>25,66</td>
<td>28,3</td>
</tr>
<tr>
<td></td>
<td>-3,80</td>
<td>-6,96</td>
<td>-7,50</td>
<td>-2,37</td>
<td></td>
</tr>
<tr>
<td>Mountain</td>
<td>27,94</td>
<td>38,14</td>
<td>49,53</td>
<td>23,21</td>
<td>30,1</td>
</tr>
<tr>
<td></td>
<td>-2,10</td>
<td>-3,52</td>
<td>-6,70</td>
<td>-2,43</td>
<td></td>
</tr>
<tr>
<td>Reservoir Borders</td>
<td>28,10</td>
<td>34,21</td>
<td>32,48</td>
<td>11,84</td>
<td>2,9</td>
</tr>
<tr>
<td></td>
<td>-8,28</td>
<td>-21,40</td>
<td>-30,20</td>
<td>-10,11</td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>24,82</td>
<td>30,79</td>
<td>44,54</td>
<td>21,37</td>
<td>10,6</td>
</tr>
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<td>-1,42</td>
<td>-3,84</td>
<td>-4,62</td>
<td>-1,61</td>
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</tr>
<tr>
<td>Veget./Brushwood</td>
<td>21,66</td>
<td>24,94</td>
<td>38,94</td>
<td>18,12</td>
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</tr>
<tr>
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<td>-3,45</td>
<td>-5,80</td>
<td>-5,23</td>
<td>-2,10</td>
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</tr>
<tr>
<td>Water</td>
<td>20,23</td>
<td>18,29</td>
<td>12,28</td>
<td>2,55</td>
<td>6,2</td>
</tr>
<tr>
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<td>-4,28</td>
<td>-8,67</td>
<td>-7,99</td>
<td>-1,69</td>
<td></td>
</tr>
</tbody>
</table>

### Table 8: Classification: Madrid, Casa de Campo

<table>
<thead>
<tr>
<th>Classes</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking</td>
<td>49,24</td>
<td>71,08</td>
<td>76,41</td>
<td>31,27</td>
<td>2,7</td>
</tr>
<tr>
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<td>-18,23</td>
<td>-24,95</td>
<td>-23,79</td>
<td>-6,03</td>
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</tr>
<tr>
<td>No Buildings</td>
<td>39,09</td>
<td>56,00</td>
<td>63,64</td>
<td>26,90</td>
<td>15,6</td>
</tr>
<tr>
<td></td>
<td>-8,23</td>
<td>-23,23</td>
<td>-17,13</td>
<td>-7,67</td>
<td></td>
</tr>
<tr>
<td>Old Buildings</td>
<td>34,68</td>
<td>46,68</td>
<td>52,04</td>
<td>20,85</td>
<td>7,8</td>
</tr>
<tr>
<td></td>
<td>-4,94</td>
<td>-7,81</td>
<td>-8,29</td>
<td>-3,17</td>
<td></td>
</tr>
<tr>
<td>Haploxerals</td>
<td>31,70</td>
<td>42,91</td>
<td>56,75</td>
<td>25,76</td>
<td>26,0</td>
</tr>
<tr>
<td></td>
<td>-4,57</td>
<td>-11,83</td>
<td>-10,75</td>
<td>-3,76</td>
<td></td>
</tr>
<tr>
<td>Parks</td>
<td>23,72</td>
<td>26,79</td>
<td>50,70</td>
<td>25,12</td>
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<tr>
<td></td>
<td>-6,15</td>
<td>-17,72</td>
<td>-19,80</td>
<td>-6,20</td>
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</tr>
<tr>
<td>Residential</td>
<td>27,03</td>
<td>34,29</td>
<td>46,67</td>
<td>21,19</td>
<td>25,2</td>
</tr>
<tr>
<td></td>
<td>-4,49</td>
<td>-14,89</td>
<td>-11,28</td>
<td>-3,80</td>
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</tr>
<tr>
<td>New Buildings</td>
<td>29,06</td>
<td>37,66</td>
<td>41,77</td>
<td>16,37</td>
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</tr>
<tr>
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<td>-6,40</td>
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<tr>
<td>Water</td>
<td>23,64</td>
<td>26,18</td>
<td>33,95</td>
<td>13,15</td>
<td>5,9</td>
</tr>
<tr>
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<td>-5,81</td>
<td>-14,43</td>
<td>-18,24</td>
<td>-11,90</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 6. - Madrid and its environment classified in 16 spectral classes by digital analysis of LANDSAT data. Date July 28, 1975
4. RESULTS AND DISCUSSION

Sixteen units spectrally different have been identified by digital analysis of LANDSAT data, as result of classifying four test sites (Retiro, Plaza de Castilla, El Pardo and Casa de Campo), which contained 32 classes (Fig. 6).

Functions MERGESTATISTICS and SEPARABILITY were used for the 16 classes, verifying that between class no. 2 ("no buildings") and class no. 13, representing Xerochrepts soils, existed a divergence of 862, which means that both classes are spectrally similar. In fact, urban areas without edifications in Madrid have soils of the Xerochrepts group in a strong proportion.

Class no. 6, defined as "Residential 1", with high density of trees (corresponding to the area of El Viso) and class no. 9, called "grass, present low values of separability; both classes with similar characteristics by the influence of vegetation in the spectral responses. This same class 6 and the class represented by mediterranean "mountain" of Quercus ilex, have quite similar values, which shows their separability of 710.

The group of Haploxeralfs soils and the class "Residential 2" have a divergence of 772, indicating that their spectral parameters are similar. As known, Madrid capital is settled on Xerochrepts and Haploxeralfs soils.

Those classes representing certain types of cover with low values of separability cannot be differentiated being sure of accuracy in the classification, based only on LANDSAT data taken July 28, 1975.

Values of divergence between other classes is higher than 1.000, and a great amount of classes have the maximum value of 2.000, indicating a perfect separability. Tables 9 and 10 shows the mean values of reflectance for each class and its variance.
### TABLE 9: CLASSIFICATION: MADRID AND ITS ENVIRONMENT

<table>
<thead>
<tr>
<th>CLASSES</th>
<th>BAND 4</th>
<th>BAND 5</th>
<th>BAND 6</th>
<th>BAND 7</th>
<th>MEAN - VARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARKING</td>
<td>49.83</td>
<td>71.73</td>
<td>75.88</td>
<td>30.63</td>
<td>-30.36 -42.77</td>
</tr>
<tr>
<td></td>
<td>75.88</td>
<td>-24.50</td>
<td>-6.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO BUILDING</td>
<td>39.06</td>
<td>55.72</td>
<td>62.17</td>
<td>25.77</td>
<td>-7.34 -20.16</td>
</tr>
<tr>
<td></td>
<td>62.17</td>
<td>-19.43</td>
<td>-9.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQUARES</td>
<td>43.64</td>
<td>63.57</td>
<td>67.17</td>
<td>27.05</td>
<td>-8.41 -9.36</td>
</tr>
<tr>
<td></td>
<td>67.17</td>
<td>-10.24</td>
<td>-3.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLD BUILDINGS</td>
<td>34.73</td>
<td>47.39</td>
<td>51.26</td>
<td>19.98</td>
<td>-5.57 -10.89</td>
</tr>
<tr>
<td></td>
<td>51.26</td>
<td>-13.17</td>
<td>-3.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEW BUILDINGS</td>
<td>29.39</td>
<td>38.82</td>
<td>41.19</td>
<td>15.65</td>
<td>-6.15 -9.73</td>
</tr>
<tr>
<td></td>
<td>41.19</td>
<td>-14.74</td>
<td>-3.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESIDENTIAL 1</td>
<td>27.50</td>
<td>34.90</td>
<td>46.96</td>
<td>21.01</td>
<td>-5.10 -15.13</td>
</tr>
<tr>
<td></td>
<td>46.96</td>
<td>-10.82</td>
<td>-3.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESIDENTIAL 2</td>
<td>33.44</td>
<td>44.64</td>
<td>57.70</td>
<td>24.55</td>
<td>-6.92 -16.16</td>
</tr>
<tr>
<td></td>
<td>57.70</td>
<td>-9.73</td>
<td>-5.19</td>
<td></td>
<td></td>
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<tr>
<td>PARKS</td>
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<td>25.19</td>
<td>47.76</td>
<td>23.47</td>
<td>-6.50 -16.32</td>
</tr>
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<td></td>
<td>47.76</td>
<td>-31.36</td>
<td>-11.22</td>
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<td></td>
</tr>
</tbody>
</table>

### TABLE 10: CLASSIFICATION: MADRID AND ITS ENVIRONMENT

<table>
<thead>
<tr>
<th>CLASSES</th>
<th>BAND 4</th>
<th>BAND 5</th>
<th>BAND 6</th>
<th>BAND 7</th>
<th>MEAN - VARIANCE</th>
<th>% OCCUPIED PER CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARKS</td>
<td>20.23</td>
<td>18.29</td>
<td>12.28</td>
<td>2.55</td>
<td>-4.28 -8.70</td>
<td>0.3</td>
</tr>
<tr>
<td>MEA1 VARIANCE</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MEAN - VARIANCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% OCCUPIED PER CLASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLASSES</th>
<th>BAND 4</th>
<th>BAND 5</th>
<th>BAND 6</th>
<th>BAND 7</th>
<th>MEAN - VARIANCE</th>
<th>% OCCUPIED PER CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRASS</td>
<td>24.61</td>
<td>29.88</td>
<td>42.99</td>
<td>19.19</td>
<td>-4.66 -10.95</td>
<td>7.3</td>
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<td>-5.42 -20.97</td>
<td>4.2</td>
</tr>
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<td>MOUNTAIN</td>
<td>27.94</td>
<td>38.14</td>
<td>49.53</td>
<td>23.21</td>
<td>-2.10 -5.52</td>
<td>8.2</td>
</tr>
<tr>
<td>BARE SOIL</td>
<td>42.30</td>
<td>64.65</td>
<td>72.16</td>
<td>31.51</td>
<td>-11.97 -25.70</td>
<td>15.9</td>
</tr>
<tr>
<td>XEROCHREPTS</td>
<td>36.98</td>
<td>53.89</td>
<td>62.87</td>
<td>28.18</td>
<td>-2.85 -6.86</td>
<td>10.9</td>
</tr>
<tr>
<td>HAPLOXERALFS</td>
<td>31.68</td>
<td>44.39</td>
<td>56.07</td>
<td>25.69</td>
<td>-4.98 -9.98</td>
<td>11.4</td>
</tr>
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<td>LAKES/STREETS</td>
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<td>30.74</td>
<td>33.84</td>
<td>12.68</td>
<td>-5.61 -16.40</td>
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<td>18.29</td>
<td>12.28</td>
<td>2.55</td>
<td>-4.28 -8.70</td>
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### Table 11. Percent Cover of Each Class

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<th>%</th>
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<td>Parking</td>
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<td>No Building</td>
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</tr>
<tr>
<td>Squares</td>
<td>7.2</td>
</tr>
<tr>
<td>Old Buildings</td>
<td>5.9</td>
</tr>
<tr>
<td>New Buildings</td>
<td>3.7</td>
</tr>
<tr>
<td>Residential 1</td>
<td>4.1</td>
</tr>
<tr>
<td>Residential 2</td>
<td>5.2</td>
</tr>
<tr>
<td>Parks</td>
<td>2.1</td>
</tr>
<tr>
<td>Grass</td>
<td>7.3</td>
</tr>
<tr>
<td>Compact Veget.</td>
<td>4.2</td>
</tr>
<tr>
<td>Mountain</td>
<td>8.2</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>15.9</td>
</tr>
<tr>
<td>Xerochrepts</td>
<td>10.9</td>
</tr>
<tr>
<td>Haploxeralfs</td>
<td>11.4</td>
</tr>
<tr>
<td>Lakes/Streets</td>
<td>1.3</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>0.3</td>
</tr>
</tbody>
</table>

### Table 12. Identification of Eight Classes

<table>
<thead>
<tr>
<th>Simplified Classes</th>
<th>Initial Classes</th>
<th>%</th>
<th>Map Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Buildings</td>
<td>Parking</td>
<td>19.6</td>
<td></td>
</tr>
<tr>
<td>URBAN</td>
<td>No building</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Squares</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>Old buildings</td>
<td>9.6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>New buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOUNTAINS AND PARKS</td>
<td>Residential 1</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Residential 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XEROCHREPTS</td>
<td>Parks</td>
<td>21.8</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compact Veget.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mountain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAPLOXERALPS</td>
<td>Base soil</td>
<td>26.8</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Xerochrepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAKES/STREETS</td>
<td>Haploxeralfs</td>
<td>11.4</td>
<td>=</td>
</tr>
<tr>
<td></td>
<td>Lakes/streets</td>
<td>1.3</td>
<td>+</td>
</tr>
<tr>
<td>RESERVOIRS</td>
<td>Reservoirs</td>
<td>0.3</td>
<td>W</td>
</tr>
</tbody>
</table>
FIG. 7: MADRID AND ITS ENVIRONMENT

CLASSIFICATION

1. PARKING
2. NO BUILDINGS
3. SQUARES
4. OLD BUILDINGS
5. NEW BUILDINGS
6. RESIDENTIAL 1
7. RESIDENTIAL 2
8. PARKS
9. GRASS
10. COMPACT VEGET.
11. MOUNTAINS
12. BARE SOIL
13. XEROCHREPTS
14. HAPLOXERALFS
15. LAKES/STREETS
16. RESERVOIRS
As result of the classification, percentage covered by each class can be used as important data at the moment of applying results (Table 11).

In conclusion, there are 16 spectral classes with four main types of cover included in the categories: urban, forest (mountain-vegetation), edaphic and hydric. (Figure 7).

A reduction in the number of classes to eight simplifies the image of the area (Fig. 8) and its interpretation. The new eight classes identified are shown in table 12.

Printed images of "Madrid and its environment" show digital displays of the area under study, geometrically corrected, in false color, and classified. The equivalence tables of symbols of computer printout, color of display and significance of each class is given. (Tables 13 and 14).

The surface included in the images (Fig. 9 and 10) has an extension of 12.267 hectares, and it represents the same area than Fig. 11, where the symbols used by the computer can be seen. Each symbol represents a surface of 1.15 acres or 0.47 hectares at scale 1:25.000.

The map printed by the computer, with eight simplified classes is more clear and schematic, offering more advantages to the not specialized user.

Applications of a study of LANDSAT data done by computer can be established as function of the mentioned objectives in this report: land use and soils classification. With this digital analysis we have established the main spectral classes (urbans, edaphics, forests and hydrics) and subclasses of Madrid environment and its area of influence (or impact).

More detailed studies in this sense could be basic for a structural planning of urban and rural areas. In the urban areas
Fig. 9.—Area of El Pardo. Date July 28, 1975
Fig. 10. Madrid and El Pardo. Classification in 8 classes. Date July 28, 1975
Figure 11. Madrid and El Pardo. Computer printout of 8 classes.
### TABLE 13. COLOR IDENTIFICATION OF 16 CLASSES

<table>
<thead>
<tr>
<th>COMPUTER SYMBOL</th>
<th>IMAGE COLOR</th>
<th>CLASS SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Dark brown</td>
<td>Parking</td>
</tr>
<tr>
<td>o</td>
<td>Light brown</td>
<td>No buildings</td>
</tr>
<tr>
<td>¥</td>
<td>Light greenish grey</td>
<td>Squares</td>
</tr>
<tr>
<td>.</td>
<td>Red</td>
<td>Old buildings</td>
</tr>
<tr>
<td>O</td>
<td>Dark rose</td>
<td>New buildings</td>
</tr>
<tr>
<td>=</td>
<td>Dark blue</td>
<td>Residential 1</td>
</tr>
<tr>
<td>-</td>
<td>Light blue</td>
<td>Residential 2</td>
</tr>
<tr>
<td>*</td>
<td>Dark green</td>
<td>Parks</td>
</tr>
<tr>
<td>/</td>
<td>Light green</td>
<td>Grass</td>
</tr>
<tr>
<td>V</td>
<td>Yellowish green</td>
<td>Compact veget.</td>
</tr>
<tr>
<td>I</td>
<td>Greenish yellow</td>
<td>Mountain</td>
</tr>
<tr>
<td>S</td>
<td>Light Beige</td>
<td>Bare soil</td>
</tr>
<tr>
<td>X</td>
<td>Yellow</td>
<td>Xerochrepts</td>
</tr>
<tr>
<td>H</td>
<td>Mustard yellow</td>
<td>Haploxeralfs</td>
</tr>
<tr>
<td>+</td>
<td>Navy blue</td>
<td>Lakes/streets</td>
</tr>
<tr>
<td>W</td>
<td>Black</td>
<td>Reservoirs</td>
</tr>
</tbody>
</table>

### TABLE 14. COLOR IDENTIFICATION OF 8 CLASSES

<table>
<thead>
<tr>
<th>COMPUTER SYMBOL</th>
<th>IMAGE COLOR</th>
<th>CLASS SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Dark brown</td>
<td>No buildings</td>
</tr>
<tr>
<td>o</td>
<td>Red</td>
<td>Urban</td>
</tr>
<tr>
<td>.</td>
<td>Light blue</td>
<td>Residential</td>
</tr>
<tr>
<td>*</td>
<td>Light green</td>
<td>Mountains and Parks</td>
</tr>
<tr>
<td>/</td>
<td>Yellow</td>
<td>Xerochrepts</td>
</tr>
<tr>
<td>=</td>
<td>Mustard yellow</td>
<td>Haploxeralfs</td>
</tr>
<tr>
<td>+</td>
<td>Navy blue</td>
<td>Lakes/streets</td>
</tr>
<tr>
<td>W</td>
<td>Dark rose</td>
<td>Reservoirs</td>
</tr>
</tbody>
</table>
exists the possibility of a cyclic checking of urban changes, observing the direction and evolution of growth in the cities.

Concerning rural areas, LANDSAT data show the possibility of an inventory of crops (classes and surfaces); damages by plagues and meteorological conditions and not cultivated surfaces classified by type of soils. Outside of knowing the land use in a certain moment, it can be known the variation of soils in time.

Advantages offered by digital analysis of LANDSAT data in the study and investigation of Earth Sciences can be translated as the possibility of selection of the date for study, cost economy per unit of surface area, easy correlation of classes and rapid development of a working program. These advantages and the possibility of studying the earth surface every 18 days justify the great number of projects envolved in the use of remote sensing technology.
DIFFERENTIATION OF CONIFERS SPECIES IN CENTRAL SPAIN
BY DIGITAL ANALYSIS OF LANDSAT DATA.

Joaquín D'Aubarede
Pilar Avizanda

Remote Sensing Laboratory
Geographic and Cadastral Institute
Madrid
SPAIN.
FORESTRY

DIFFERENTIATION OF CONIFERS SPECIES IN CENTRAL SPAIN BY.
DIGITAL ANALYSIS OF LANDSAT DATA.

By Joaquín D'Aubarede and Pilar Avizanda
Remote Sensing Laboratory
Instituto Geográfico y Catastral
Madrid.

1. INTRODUCTION

This work is carried out with the purpose of differentiating conifers species in Central Spain, by means of digital processing techniques applied to LANDSAT MSS information.

The analysis done pretends to establish spectral differences in the responses of Pinus pinea L., Pinus pinaster Sol. and Pinus sylvestris L. when studied in their natural habitats of the forests around Madrid Province.

A supervised classification of different species, by selection of training fields, is the technique applied in this report to the test sites defined in Sierras of Guadarrama and Gredos.

2. BIOLOGICAL AND ECOLOGICAL BACKGROUND

In this work it is intended to differentiate the following conifers species in Central Spain by means of digital, analysis of LANDSAT data:
- Pinus pinaster Sol.
- Pinus pinea L.
- Pinus sylvestris L.
Such species are well represented in Central Spain, around the Sierras of Guadarrama and Gredos, which are the areas of study. They present thick masses of pinus in their natural habitat (figure 1), with the following environmental conditions:

**P. pinaster** Sol. It covers in the Iberian Peninsula broad extensions of mountains; namely in the Sierras of Guadarrama and Gredos, living in soils of siliceous nature. The average altitude where it can be found at the area under study is 1,000 m, forming mixed forests with the *Pinus sylvestris* in Sierra of Guadarrama. It is an species of vigorous nature and fast growing, according to the good lighting conditions that requires. Flowering season is from March to May, depending on the severity of the moderate climate. The sheated needles have a length of 15-27 cms, being of a high dark-greenish colour.

**P. pinea** L. It is distributed all over the mediterranean coast, living at an average height of 1000 m. In the Iberian Plateau it can be found on sandy and deep soils, while in Central Spain it does not surpass the altitude of 1000 m and forms mixed forests with the *Pinus pinaster*. This is a tree of second magnitude and fast growing which has a vigorous nature and needs good lighting conditions. Flowering season is from March to May. The needles have a length of 10 to 20 cms in greenish-blue colour.

**P. sylvestris** L. In Spain it covers a broad area from the Pyrenees mountains to Sierra Nevada, forming thick forests in the Central ridge, with optimum growing conditions in Navafria and Balsaín (area of study in this work). Living in siliceous and clayish soils, its optimum altitude attended is 1,500 m. This species requires medium lighting conditions and it has a quite vigorous nature. Flowering season is from May to
Fig. 1.—Test sites selected in Sierras de Guadarrama and Gredos for analysis of conifers species
June. Although needles have a normal length of 3 to 10 cms, in Spain they do not surpass 3 to 6 cms, being of greenish-gray to glaucous colour.

3. METHODOLOGY

Differentiation of the three main conifers species existing in Central Spain was intended by the use of digital MSS information as basic input. From the library of the Remote Sensing Laboratory was analyzed LANDSAT tape E-1228-10325, corresponding to the month of March 1973, which was taken at the time of the flowering period of species. Such image has a sun elevation angle of 37 degrees and no cloud cover.

As ancillary information it was used the Forestry Map of Spain, which is at scale 1:400,000 and has provided the basic ground truth over test sites. Some photointerpretation of recent LANDSAT images was also carried out through a DOT color composite viewer (reference 1) in an effort to keep up to date the information of the Forestry Map. Once defined the location of the working areas, according to criteria of good identification of representative training fields (figure 1), a digital analysis of the original LANDSAT tape was done.

The technique used was a supervised classification of the zones, taking as training class different species of conifers. This work was done at the IBM-Scientific Center of the Autonomous University of Madrid; where ERMAN-II program is available, operating on an IBM 360/65 computer interfaced to an interactive television terminal RAMTEK.

As a first stage was intended to establish a difference between both species Pinus pinaster Sol. and Pinus pinea L.
Fig. 2.—Training fields corresponding to test-site no. 1
Test site no.1 was selected for this purpose (figure 1), and four training field were chosen on it, representing the items indicated in table 1.

<table>
<thead>
<tr>
<th>Field name</th>
<th>Class identification</th>
<th>Class symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEVE</td>
<td>Snow</td>
<td>NIEV</td>
</tr>
<tr>
<td>PINASTE</td>
<td>Sun exposed Pinus pinaster</td>
<td>PSOLSO</td>
</tr>
<tr>
<td>PINASTI</td>
<td>Pinus pinaster in shadow</td>
<td>PINBRA</td>
</tr>
<tr>
<td>PINEA</td>
<td>Sun exposed Pinus pinea</td>
<td>PNEA</td>
</tr>
</tbody>
</table>

Table 1. Correspondence of training fields name and classes

In figure 2 is indicated the location of training fields. The calculation of statistics corresponding to such training fields in all four bands MSS produced the results indicated in figure 3; where the mean and standard deviation values are represented as output menu of the interactive television terminal.

From the analysis of figure 3 it can be anticipated that the spectral response of both species is very characteristic in band 4 (corresponding to channel 1), because the low value of their standard deviation. As the mean values show very similar in all four bands MSS, differentiation of the species seems to be difficult. At this point, histograms were obtained for the three classes identified in each LANDSAT spectral band (figures 4, 5, 6 and 7), corresponding to their training fields.

Although results expected were not very promising, because the strong overlap of spectral responses, a classification of the area under study was done by pattern recognition. The result of such classification is indicated in figure 8, where correspondence of colors and classes is represented at table 2.
### Fig. 3.—Mean and standard derivation values of training fields

<table>
<thead>
<tr>
<th>CHANNEL NUMBER</th>
<th>FIELD NIEVE (406)</th>
<th>FIELD PINASTE (369)</th>
<th>FIELD PINASTI (104)</th>
<th>FIELD PINEA (506)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLASS NIEVE</td>
<td>CLASS PINASTE</td>
<td>CLASS PINASTI</td>
<td>CLASS PINEA</td>
</tr>
<tr>
<td></td>
<td>MEAN</td>
<td>ST DEVL</td>
<td>MEAN</td>
<td>ST DEVL</td>
</tr>
<tr>
<td>1</td>
<td>106</td>
<td>34</td>
<td>19</td>
<td>79</td>
</tr>
<tr>
<td>2</td>
<td>104</td>
<td>66</td>
<td>14</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>95.71</td>
<td>20.60</td>
<td>26</td>
<td>62</td>
</tr>
<tr>
<td>4</td>
<td>36.40</td>
<td>11.05</td>
<td>15</td>
<td>70</td>
</tr>
</tbody>
</table>

**Table:** Mean and standard deviation values for different classes and training fields.
Differentiation of Pinus sylvestris and Pinus pinea was intended on test site no. 2 (figure 1), with a new LANDSAT image dated March 7, 1973 (E-1227-10271), with sun angle elevation of 37 degrees similar to the previously used image (E-1228-10325) for test site no. 1. As both images were taken with an interval of 24 hours, the vegetative status of conifers species was in similar conditions.

A supervised classification was done in the new area of study with two training fields of P. sylvestris and P. pinea.L. Computation of statistics conducted to the result indicated in table 3.

<table>
<thead>
<tr>
<th>class symbol</th>
<th>color</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEV</td>
<td>blue</td>
</tr>
<tr>
<td>PSOLSO</td>
<td>green</td>
</tr>
<tr>
<td>PINBRA</td>
<td>cyan</td>
</tr>
<tr>
<td>PNEA</td>
<td>red</td>
</tr>
</tbody>
</table>

Table 2.

<table>
<thead>
<tr>
<th>Band</th>
<th>Field PINEA</th>
<th>Field SILVES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev.</td>
</tr>
<tr>
<td>4</td>
<td>24,26</td>
<td>2,16</td>
</tr>
<tr>
<td>5</td>
<td>21,33</td>
<td>3,16</td>
</tr>
<tr>
<td>6</td>
<td>31,57</td>
<td>4,07</td>
</tr>
</tbody>
</table>

Table 3. Mean and standard deviation values of training fields.
Fig. 4.—Histogram of classes in band 4

Fig. 5.—Histogram of classes in band 5
Fig. 6—Histogram of classes in band 6

Fig. 7.—Histogram of classes in band 7
Fig. 3. Result of the supervised classification in test-site no. 1. Black color represents threshold value.
Band 7 was not available for this classification. The values of mean and standard deviation obtained in the training fields show that a differentiation of both species of conifers is possible when based on a supervised classification of LANDSAT data. In figure 9, 10 and 11 the histogram values for each band are represented.

4. RESULTS AND DISCUSSION

At the flowering season of Pinus pinaster and Pinus pinea it was not possible to differentiate both species in Central Spain by digital analysis of LANDSAT data. Such result could be due to the fact that both species have the same biotop. As both pinus have a strong need of light for attending their development and climax, their crowns and cortical systems cannot afford a competition with other trees of the same species. Their forests have to be open, with the number of trees per hectare being low when compared to other species of different nature, like the Pinus sylvestris in normal closeness. Such circumstances force the existence of open spaces between trees; soil or open space which, due to the biological needs of both species and the geological nature of the central region of Spain, is similar for them. These reasons indicate that texture of the species as seen by LANDSAT must be quite homogenous in both cases.

An individual analysis of each species shows that a certain similarity is observed in their needles, of approximate length, and in their greenish-blue color, which produces quite similar reflectances in band 4 (green region of the spectrum). The histograms of figures 4, 5, 6 and 7 show that a discrimination of Pinus pinaster and Pinus pinea is not possible in the LANDSAT
Fig. 9.—Histogram of classes in band 4

Fig. 10.—Histogram of classes in band 5

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Fig. 11.—Histogram of classes in band 6
image studied, because the high amount of pixels that belong to both species and have similar values of reflectance. Such mixed spectral response appears also in the training fields of Pinus pinaster in shadow and in sun light, being in the second case more difficult to find out a difference with Pinus pinea class.

Differentiation of P. sylvestris and P. pinea was much better achieved, because the biological and ecological needs of both species are not the same. As the flowering period of P. sylvestris is from May to June, and the movement of the sap begins on it two months latter than in P. pinea, their reflectance curves do not seem to be equal, nor is their color.

As P. sylvestris is a species with medium lighting conditions requirements, it has a higher density of trees per hectare than P. pinea; which should have an important effect in the texture of the crowns when observed at satellite altitudes. Band 4 seems to contain better MSS information than bands 5 and 6 for differentiation of both species.

The conclusions presented are only defined for Central Spain, and they do not apply in general to P. sylvestris L. and P. pinea L. species, because such species in other areas with different factors (climatology, ecology and geology), could have different spectral responses than here evaluated.

Aknowledgement

Aknowledgement is given to Jorge González, of IBM-Scientific Center, for his technical support in the supervised classification of digital data.
References

1 - J. D'Aubarede and P. Avizanda "Application of LANDSAT-2 data to updating forestry maps in the central region of Spain". Third Quarterly Report, NASA project no. 28760, Instituto Geográfico y Catastral, Madrid.
DETERMINATION BY MEANS OF LANDSAT IMAGES OF DIFFERENT GEOLOGICAL STRUCTURES IN THE CENTRAL AREAS OF IBERIAN PLATEAU.

M. Alía  
C. Martín Escorza  
A. G. Ubanell  
L. Muñoz

Internal Geodynamics Department  
Complutense University of Madrid.  
SPAIN.
G E O L O G Y

DETERMINATION BY MEANS OF LANDSAT IMAGES OF DIFFERENT GEOLOGICAL STRUCTURES IN THE CENTRAL AREAS OF THE IBERIAN PLATEAU.

By M. Alía, C. Martín-Escorza, A.G. Ubanell and L. Múñoz
Cátedra de Geodinámica Interna
Universidad Complutense
Madrid.

SUMMARY

Starting with the observation of the LANDSAT images, new structures of tectonic origin have been able to be determined in the Iberian Plateau.

In the first place, we would point out the megastructure "Bóveda Castellano-Extremadura", of elliptical form and which, because of its amplitude (some 350 kms. as minimum in its largest axis, orientated to the NE) should be considered as lithospheric scale. Its origin (ALIA, M. 1976, b) can be related to the interactive processes between the veins and the crust which gave way to an arching initially, which was followed by a distension process with the formation of valleys and basins during the upper Tertiary. In this great structure, two areas are differentiated; one septentrional, which is more complex and accidented, and the other, more homogenous, meridional. Both are separated by the "Banda Estructural de Toledo" (ALIA, M. 1972) of an E-W direction.

Forming part of the most heterogeneous septentrional unit, and also by means of LANDSAT images, the "Halo Estructural de Guadalix" has been differentiated; an annular structure of concentric rings with a maximum radius of 40 kms. located North of Madrid.
Distinct alignments localized in the granite-metamorphic Basement of the Central System have also been differentiated and evaluated with relation to the field data, with a diagram offered of the set of observations.

Also, the best band relations have been found to obtain optimum results in areas of this type, and thus in a zone of the Iberian Plateau, geological structures have been determined and the different types of lithologies.

1. INTRODUCTION

The team studies being made by the members of the Department of Internal Geodynamics of the Complutense University of Madrid in the central areas of the Iberian Plateau include: analysis of the structures in fayed veins, detections of alignments of tectonic origin in zones covered by non-tectonized neogenic sediments, raising maps from the ceilings of the basement in these last zones by geophysical methods (magnetometrics and gravimetrics, mainly) and gravimetric profiles through zones with fayed and unfayed basement. These studies have allowed obtaining a certain structural and tectonic conception of the above mentioned areas.

These discoveries have been greatly enriched by the consequences obtained from the observation of LANDSAT images, which were provided by NASA through the Geographic and Cadastral Institute of Spain in accordance with Project no. 28760 signed between both agencies.

The geological results obtained from these images have allowed integrating some of the facts observed in the field, to facilitate the vision of the unit of some already known structures, to make them coherent with others newly detected.
Figure 1

ORIGINAL PAGE IS
OF POOR QUALITY
Figure 2

ORIGINAL PAGE IS OF POOR QUALITY
by LANDSAT images, and to make even more ample some of the preconceived investigation lines.

It has been very interesting to be able by means of such images to establish the existence of a cortical megastructure ("Extremenian-Castillian Vault", ALIA, 1976, a, b) which, with an elliptical form and the major axis orientated following a NE-SW direction, crosses a great part of the inside areas of the Iberian Plateau.

2. DESCRIPTION OF THE AREA STUDIED, MATERIAL, METHODS AND TECHNIQUES USED.

The area studied (figure 1) corresponds to the central regions of the Iberian Plateau and fundamentally include the Central System, the Mountains of Toledo and the two Valleys of the Tajo and the Duero. The Central System and the Mountains of Toledo are made up of granite and metamorphic rocks, formed in the Hercinian Cycle, and in the Valleys of Tajo and Duero crop up, in the majority, covering materials deposited during the Tertiary.

In the Central System, two great alignments can be differentiated: The Sierra de Gredos, situated to the West and the Sierra del Guadarrama, on the oriental side. It should likewise be pointed out that the Valley of Tajo is limited in its meridional part by another large granite-metamorphic alignment of the Hercinian Cycle: The Mountains of Toledo.

All of these zones are covered by images E:1228-10325, 1229-10384; 1227-10271; 2170-10204; 2367-10122, of which the most frequently used channels were bands 5, 6 and 7, which have been found as the best for geological examination.

The interpretation and analysis has been made through the direct observation of images available in different sizes,
Figure 3
on which transparencies were superimposed and lines were marked when due to geological accidents of tectonic origin. The analysis, the ponderation, integration and coherence of such structural lines with the observed and known facts of the land, have made possible obtaining greater structures with the results stated here.

In the zone of the Valley of Tajo an interactive RAMTEK Terminal has been used, connected to an IBM 360-65 computer. The terminal comprises a conversational screen and an image display unit (color-TV), as well as a memory bank to accumulate images at 8 bits, with 16 levels in each of the three tube. The entire system is governed by the ERMAN-II programme (L. MUÑOZ, 1976 - Second Quarterly Report, fig. 4).

3. RESULTS

3.1. Application of the above mentioned methods to a composite of the images E-1228-10325 and E-1229-10384 in any of its channels, but specially in bands 5 and 7, has allowed (ALIA 1976 a, b) to interpret that the dominant structures of the unit observed in the images correspond to an ample arching which affects the terrestrial coverage in the regions of the Iberian Plateau, and which has been called "Extremenian-Castillian Vault" (op.cit. page 229). This megatructure (figure 1) is equally developed in the regions where the materials of the Hercinian basement are fayed (Central System and Mountains of Toledo) as in those others where said basement stays hidden under the coverings of posterior sediments.

The defining elements in the case of the fayed basement are fundamentally provided by fractures which, with their preferent alineations and continuity, sketch the greater structure to which they belong. Many of these fractures are used by the
fluvial network at the present times. In the case of the zones with sedimentary coverage, equally aligned elements are presented which correspond to and are the surface reflection of; through the covering, existing alignments in the hidden basement, in accordance with correlations which have already been established for the zones of the Valley or Tectonic Depression of the Tajo (ALIA et al., 1973; CADAVID et al., 1967; MARTIN ESCORZA, 1976 a, b; MARTIN ESCORZA et al., 1972, 1973). Such alignments under cover are generally expressed by lateral changes of facies and powers which are also found following the lines represented in the cartography. Some of these lines are weakness bands which equally use the present or subpresent fluvial network.

Figure 2 corresponds to the image E-1228-10325-7 taken by LANDSAT-1 of the central region of Spain. Figure 3 schematically marked the main structural alignments which are integrated for this region into the Extremenian-Castillian Vault.

As observed in figures 1 and 3, the Extremenian Castillian Vault is affected in the middle by structural alignments with a parallel E-W direction, which belong to an important existent alignment also on a Peninsular scale, already detected by ALIA (1972) and known since then with the name of "Banda Estructural de Toledo". The influence of this tectonic structure on the "Extremenian-Castillían Vault" is shown in its middle areas and thus divides it into two large units: the septentrional, with visible and numerous arched alignments (figures 1, 2 and 3) and the meridional with a lesser proliferations of defining alignments (figure 1). The "Banda Estructural de Toledo" interrupts the Southern directed continuity of some main alignments of the septentrional unit, others are slightly detoured and others
Figure 5

- Tertiary sediments
- Ordovician
- Faults or fractures
- Idem, probable
- Aplitic dyke

A.G. UBAELL 1976
such as that which limits the Vault on its northwestern border, stays neatly marked on the North as well as the South. This line, which in figure 1 is indicated by letters D.P., corresponds to the well-known and important Dique de Alentejo-Plasencia (GARCIA DE FIGUEROLA, 1963, 1965; GARCIA DE FIGUEROLA, et al., 1974).

In the southeastern part of the Vault, the most important defining line is found to be in direct relation with the presence of the sedimentary sub-basin Badajoz-Cijara (see figure 1).

The megastructure thus defined as "Extremenian-Castillian Vault" is a tectonic-structural element of prime importance in the Iberian Plateau and by itself indicates, it seems to us, a directing model, from which the investigations for profiling and concreting the lesser structures and acompanantes of this which we consider the main one, can be proceeded with.

3.2. In this respect we offer here (figure 5) and as a result of this Project, a promenorization of the observable alineations in the unit of the hercinian flayed basement which constitutes the Central System (UBANELL, 1976). In order to obtain this, we have used the images E-1228-10325, E-1229-10384 and E-1227-10271 in bands 5 and 7. (figure 4). The direct knowledge in the field of these regions has permitted improving and giving a greater significance to these structural ranges, in comparison with the results offered by other authors (as for example BISCHOFF, 1975). With more recent images of the same zone it is possible to extract a greater detail, and thus in the structural scheme of alineations of figure 6, the E-2170-10204-7 has been used with a date of July 1975, obtained by LANDSAT-2 and which still covering the same area as that in figure 2, gives a clearer view.
The noticeable improvement in the quality and clearness of
the LANDSAT images is appreciated, from the first ones
received up to the most recent ones, as they have permitted
differentiating other lesser structures, which would otherwise
have remained undetected.

3.3. Such succeeds in the regions situated to the North of
Madrid, where the images E-2223-10135; 2187-10143; 2169-10145,
in their different bands 4, 5, 6 and 7, would not suggest
a marked structural form. Nevertheless, the careful observation
of the most recent image (July, 1976), the E-2367-10122-7, has
made it possible that in said regions an annular structure has
been determined which affects the materials of the hercynian
basement in the Central System as well as the sedimentary neogene
covering of the Valley of Tajo, in this case composed mainly
by arcosas (figure 7). This structure (Figure 8) has been named
the "Halo estructural de Guadalix" since the town of Guadalix
is the most central point of it. Its average radius is 30 to
40 km. and its outside ring reaches in effect the city of
Madrid. This structure is not a complete ring, since in its
most septetrical part, it is cut off by the larger fracture,
with a NE-SW direction which limits the meridional edge of
the Central System.

As can be directly observed in the zone of the studied image
(figure 9) many of these curved alineations correspond to
secondary sources of the present fluvial network, but the
clearest defining elements and also those which are most
numerous correspond to streams and fluvial interlickings of
even lesser order and importance (figure 10). Such streams
are arranged making up a unit which is only explicable by
the existence of the cited structure and in some concrete
Figure 7
areas they offer a good example of the influence of the "Halo Estructural de Guadalix" (figure 11) on the hydric flux of this category.

3.4. Apart from all these structures of different importance and scale described up to now, we have tried to testify, in a very concrete area, where we likewise have sufficient field data, the prominence or mortification of determined and contrasting structures depending on the band-ratio. The possible application of the handling of this technique by means of a RAMTEK Terminal in structural geology, is a function of the results obtained in the utilization of different relations of channels, each one of which can visualize in a different way the same structures. This technique was made possible through the IBM-Scientific Center of the Autonomous University of Madrid.

The area selected was Campo Arañuelo, a tertiary sub-basin (figure 12) located some 250 kms. to the West of Madrid (see figure 3) and concretely part of its meridional limit, where it has been proved (figure 13) that the granite-metamorphic hercynian basement which forms part of the Mountains of Toledo, is found to be in contact with the non-consolidated sedimentary crust, by means of fractures and robbles of almost the same directions (MUÑOZ, L. 1976, a, b) which delimit three rigid basement units which "penetrate" in the area of the covering, like piano keys. For this reason, we have called them "Navalmoral Key", "Berrocalejo Key", "Oropesa Key" from the West to the East respectively. Using the image E-1228-10325, of 8 May, 1973, with a Solar Elevation of 37° and Azimuth of 142°, it was processed in such a way that the color images obtained on the screen were a result of a histogram, made of the radiation levels in each of the bands to be represented and where the levels
are assembled in 8 grades of intensities for the red and green, and four grades for the blue. This assembly is made in such a way that there are approximately the same number of pixels in each. This condition is imposed for the maximization of the information.

Some 40 combinations of band-ratios are examined at length, on the grounds of this determinative.

For false color, we consider as best for the study of the lithologies and linear structures, the following combinations of ratios (MUÑOZ, 1976, a):

a) \( R \quad \frac{4}{G} \quad \frac{7}{B} \quad \frac{7}{4} \) which are given by the following coefficients:

\[
\begin{align*}
R &= I_1' = I_4 \\
G &= I_{13}' = I_7 \\
B &= I_{14}' = 64 \frac{I_7}{(I_4 - 1)}
\end{align*}
\]

b) \( R_4 \quad G \quad \frac{7}{4} \quad B \quad 7 \) given by:

\[
\begin{align*}
R &= I_1' = I_4 \\
G &= I_{14}' = 64 \frac{I_7}{(I_4 - 1)} \\
B &= I_{13}' = I_7
\end{align*}
\]

4. INTERPRETATION AND DISCUSSION

The formation of the "Extremenian-Castillian Vault" probably occurred during the Oligocene-Miocene (ALIA, 1976, a, b), although in part it must have been influenced by more antique structural directrices (Banda Estructural de Toledo, Dique-
and associated fracture of Alentejo-Plasencia, etc.)

During the Oligocene-Miocene periods and after a generalized elevation phase, another of decompressed collapse followed, along the lengths of the blanks of this megastructure. This collapse would mainly affect the great septentrional unit which would thus be left fractioned in smaller units and blocks. These movements of decompression would individualize the large collateral tertiary basins, and within them would, in turn, provoke other movements of blocks of a lesser order which, following lines of weakness parallel to them, would provoke variations of facies and thickness in the correlative sediments, which were then deposited there. Furthermore, the differential movements seem to have kept on up to most recent times, as is deduced for example by the adaption and asymmetric morphology which is presented by many of the fluvial courses which are adjusted to the parallel lines to said Vault.

The determination of the "Extremenian-Castillian Vault" by means of the LANDSAT images, also seems to find support in the results obtained in 1966 by the Hawaii Institute of Geophysics, whose map of Anomalies of Bouguer of the Iberian Peninsula is partially reproduced in figure 14. As can be seen by comparing this figure with figure 1, some of the isoanomalies of this map closely correspond to the structures defined in the "Extremenian-Castillian Vault" and the "Banda Estructural de Toledo", and we also observe a greater complexity and irregularity in the distribution of the isoanomalies for the septentrional half of the Vault; on the contrary, in the meridional half, in the LANDSAT images as well as in the map of anomalies of Bouguer, there is less accidentation. These facts and correlations can be interpreted as a consequence of the differential movements continuing up to present times.
Figure 10

ORIGINAL PAGE IS OF POOR QUALITY
The geographical amplitude covered by the megastructure "Extremenian-Castillian Vault" (its greatest axis is more than 250 km. long) permits us to suppose that the originating cause must have affected profoundly not only the continental crust but also the underlying mantle (ALIA, 1976, a, pag. 236). It is thus a phenomenon on a lithospheric scale in which we can hypothetically find two solutions: 1) The lithosphere submitted to compression forces becomes so deformed that it becomes vaulted, and then has a passive behavior with the covering. 2) The mantle is that which vertically pushes the superincombent lithosphere producing the vaulting.

In the first case the horizontal pushes would possibly come from the meridional regions of the Béticas, whose greater structures are at long range, parallel to the greatest axis of the Vault.

In the second case it could be admitted that the activation in the mantle of a "plumes" or similar type, could be related to the generating mechanism of this megastructure.

These ideas on the possible generating mechanisms of the "Extremenian-Castillian Vault" are on the other hand congruent with the results obtained in the most localized investigations made in these regions.

In effect, with the tectonic model explained above, the origin of an annular structure with concentric rings of dimensions of 30-40 kms., as in the case of the "Halo Estructural de Guadalix" (MARTIN ESCORZA), 1976, c) could well correspond with the final sinking phase, by decompression, admitted for the "Extremenian-Castillian Vault", mainly in its septentrional half. The fact that the annular alineations of the Halo have so much effect on the metamorphic rocks of the Cerro de San Pedro, which belong to the hercinian basement of the Central System, as well as to the northern zone of Madrid which is
already covered by Neogene sediments and where, furthermore, by geophysical methods a sedimentary sub-basin has been discovered (GARCIA SEÑERIZ, J., 1941; CADAVID, S., 1973), with a greater thickness of neogene deposits (MARTIN ESCORZA, 1976, b) permits us to relate this sinking of the "Halo Estructural de Guadalix" with the general collapse of the "Extremenian-Castillian Vault".

The generating mechanism of this structure could be conceptually similar to those phenomena which are caused by decompression, immediately after a subterranean nuclear explosion, which provokes a crater with concentric circular structures (in BOLT, 1976, fig. 3.3).

As we have already said, the "Halo Estructural de Guadalix" is not a complete concentric ring (figure 8), but rather almost half of its septentrional part is cut off by the NE-SW fracture which limits the meridional edge of the Central System. We believe that this could be due, or in the case of approximate contemporaneity of both processes, to the greater fracture NE-SW absorbing the stresses and would make the penetration toward the Northwest of the concentric structures of the Halo more difficult. Or in the case in which it had moved before as an inverse robble (BENAYAS, et al., 1950; SAN MIGUEL et al., 1956; MARTIN ESCORZA, 1976, c) cut off in some way the annular structure leaving only its meridional part visible.

Either way, the complete significance and the total circumstances which motivated the existence of the "Halo Estructural de Guadalix" must be cleared up more profoundly since, in effect, the probable sinking which originated them, could have used or have been favored by pre-existing posthercinian structures. On the other hand, the present incipient development of the fluvial network on the neogene sediments, in accordance with
Basement-Tertiary distribution defined from 1G ME maps

Figure 12
The concentric alignments (see figure 10, 11) allows the logical supposition that said Halo remains active in some way at the present time.

Undoubtedly everything makes us suppose that this structure, which in its maximum radius reaches the capital of Madrid affecting a great area in industrial and social expansion, can have a special significance in the field of construction as well as in the search for hydric and mining resources.

In figures 5 and 6 all the acknowledged fractures have been positioned, among which are some which correspond to or have been activated during the formation of the "Extremenian Castillian Vault", and others which, being older, have nevertheless not entered into play in this megastructure.

Thus, the NE-SW fractures, whose main alignments are the Dique of Alentejo-Plasencia and the roble which meridionally limits the Central System, corresponds to tardi-hercinian times (PARGA, 1969) and belong to a system of sinistral wrench faults (ARTHAUD and MATTE, 1975), in the mentioned NE-SW direction. In the LANDSAT images, they are easily recognizable for their folded formations made up of quartz from the lower Ordovician period (figure 5).

In the case of the fault line associated with the Dique de Alentejo-Plasencia, the net movement suffered by this formation of ordovician quartz from one to the other side of the fault is 4-7 kms., and even considering the effect of the arching, this value can be really established as some 23 kms. (UBANELL, 1976).

Another great accident with this same direction is represented by the meridional edge of the Central System. During tardi-hercinian times it acted as a dextral wrench fault in a first stage, and later as a sinistral. It has moved, as we have said
CUENCA DE CAMPO ARAÑUELO

Lineaments and Basement-Tertiary distribution as interpreted from the Landsat-1 imagery.

Figure 13

Tajo (with Valdecañas dam) and Tietar rivers are represented.

Basement-Tertiary contact

Faults and fractures

Scale: 0 5 10 15 Km
during the Alpine cycle, in accordance with an inverse fault, on top of Miocenean sediments. Finally, movements have been detected during the Quaternary which produced deposits of terraces and variations in the fluvial network (PEDRAZA, 1976).

The NW-SE fractures make up a combined system with the above mentioned NE-SW direction, although they are not as developed. The sinistral movement of the NE-SW faults provoke phenomena of tension in N-NE, which are frequently taken advantage of by quartz fillings, following numerous but not very long dikes.

The E-W direction alineations should be attributed to the penetration in the Central System of fractures which form part of the tectonic unit known as the "Banda Estructural de Toledo" (ALIA, 1972); and the N-S directions are of special interest since they continue and penetrate into the areas occupied by the sedimentary deposits of the Duero Basin (figure 6).

5. CONCLUSIONS

Making use of the images proportioned by LANDSAT, we have been able to determine:

- A lithospheric megastructure with NE-SW direction of more than 350 km. long in its major axis, the "Extremenian-Castillian Vault", defined by important structural alineations on its flanks and in which it is possible to differentiate a large more accidented and complex septentrional area, from a meridional area with less structures; both areas are delimited by alineations with E-W direction belonging to the "Banda Estructural de Toledo".

- We must suppose that the origin of the Extremenian-Castillian
Figure 14
Vault is due, because of its scale, to processes of lithospheric scale, with movements produced by fields of vertical or horizontal stress, but that, in any case, provoked a first stage of arching against gravity, with a later relaxation and differential sinking, in large blocks, during the Oligocenian-Miocenean period.

Perhaps related to that second stage of generalized decompression of the Extremenian-Castillian Vault, we should inject the process which gave way, in the septentional area of said Vault, to the "halo Estructural de Guadalix" of more reduced dimensions (40 km. of maximum radius).

The fayed Hercinian Basement of the Central System, is affected by numerous alineations of different sizes among which can be differentiated those which originated in tardi-hercinian periods, from those which originated during the Alpine cycle.

The attestation in a reduced area in which were found many of the geological characteristics mentioned above has permitted establishing that the best combinations of ratios for the study of lithologies and linear structures in these areas is (MUÑOZ, 1976, a):

\[
\begin{array}{ccc}
R & 4 & G & 7 & B & 7/4 \\
\end{array}
\]

and

\[
\begin{array}{ccc}
R & 4 & G & 7/4 & B & 7 \\
\end{array}
\]
Figure 1.—Main defining structural alineations of the "Extremenian-Castillian Vault" which appears practically divided in two by the E-W alineations of the "Banda Estructural de Toledo". In white: main zones of the hercinian basement related to the Vault. The broken lines represent probable structural alineations which are more peripheral.

M = Madrid; TO = Toledo; SA = Salamanca; AV = Avila; SG = Segovia; ZA = Zamora; VA = Valladolid; SO = Soria; GÜ = Guadalajara; CR = Ciudad Real; CC = Caceres; BA = Badajoz; D.F. = Dique de Plasencia; Ci = Cijara; (according to ALIA, 1976 a, b).

In the upper box we have marked the area covered by this figure on the Iberian Peninsula.

Figure 2.—Image E-1228-10325-7 taken by LANDSAT-1 in March 1973 on the central zone of the Iberian Peninsula. M = Madrid; SA = Salamanca; AV = Avila; SG = Segovia; TO = Toledo. The white areas correspond with the areas of snow in the Mountains of Gredos and Guadarrama.

Figure 3.—Diagrammed representation of some of the visible structures in the figure 2 and which define the septentrional part of the "Extremenian-Castillian Vault". In white: zones of the flayed hercinian basement; in white: covered zones. The thickly drawn lines with an E-W orientation correspond to the so called "Banda Estructural de Toledo". ALIA (1972) (According to ALIA, 1976 a, b) M = Madrid, AV = Avila, TO = Toledo, SG = Segovia, SA = Salamanca. Furthermore: Depresión del Duero = Duero Basin; Depresion del Tajo = Tajo Basin, Meseta Toledana = Meseta of Toledo.
Figure 4.- Mosaic of the LANDSAT images E-1228-10325, E-1229-10384 and E-1227-10271, on the central parts of the Iberian Peninsula. M = Madrid, SA = Salamanca.

Figure 5.- Observable alignments in the unit of the hercynian flayed basement which constitutes the Central System.

Figure 6.- Detailed diagram of the alignments which are visible on the Hercynian basement of the Central System from E-2170-10204-7 obtained by LANDSAT-2 in July, 1975. (According to UBANEL, 1976).

Figure 7.- Geological sketch of the area where the concentric annular structure named "Halo Estructural de Guadalix" is inserted (MARTIN ESCORZA, 1976, c). The geological data offered here have been collected from: APARICIO et al., 1975; APARICIO et al., 1973; BABIN VICH, 1971; DE LA CONCHA, 1962, 1963; FEBREL et al., 1958; FUSTER and FEBREL, 1959; HERNANDEZ-PACHECO, F., 1965; MARTIN ESCORZA, 1976, b.

Figure 8.- Structural lines obtained from the observation of the zone represented in figure 9, and which define an annular structural complex of concentric lines which has been named "Halo Estructural de Guadalix" (according to: MARTIN ESCORZA, 1976, c).

Figure 9.- Section of NASA image E-2367-10122-7 which has been studied and whose situation in said image is expressed in the small figure of the lower right hand side.

Figure 10.- Fluvial network of the zone occupied by the section of figure 9. This fluvial network has been obtained from a topographical map at scale 1:100,000. As can be observed,
the secondary and tertiary networks are those which in some cases are defining curved alignments, corresponding to the "Halo Estructural de Guadalix". (According to MARTIN ESCORZA, 1976, c).

Figure 11.- With much greater clarity, the secondary fluvial network obtained in this case from a map at scale 1:50.000, which unmistakeably indicates to us in close areas and to the North of Madrid, the curved structures which define the "Halo Estructural de Guadalix". (According to MARTIN ESCORZA, 1976, c).

Figure 12.- Tertiary sub-basin of Campo Arañuelo, located 250 kms. West of Madrid.

Figure 13.- Meridional limit of the Campo Arañuelo Tertiary sub-basin.

Figure 14.- Central Zone of the Map of Anomalies of Bouguer for the Iberian Peninsula, done by the Hawaii Institute of Geophysics, 1966. Curve interval = 13 miligals. The same symbols for the capitals as in the above figures and also CU = Cuenca.

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SOME GEOMORPHOLOGICAL ASPECTS OF LANDSAT-2 IMAGES OVER CENTRAL WESTERN SPAIN.

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SOME GEOMORPHOLOGICAL ASPECTS OF LANDSAT-2 IMAGES OVER CENTRAL WESTERN SPAIN.

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In this paper is analyzed the geomorphological characteristic of LANDSAT-2 imagery and, as an example, some photointerpretation work is presented from images no. E-2333-10421, E-2171-10262 and E-1229-10384 (figure 1).

It has been intended to view relief, taking adjacent images with 10% overlap as stereoscopic pairs. As this is also possible with consecutive images taken during a North-South polar orbit overpassing the country, it can be established that the necessary relief vision for geomorphological interpretation can be obtained in 2/3 of the total surface of an image. Thus, relief has been inferred. Date, hour, and sun angle are important points to consider for viewing an image with a right relief illusion.

Another technique possible for geomorphological interpretation is looking South LANDSAT images from the upper side. That way, an experienced eye can see relief. Logical thinking is another aid for relief interpretation: water courses and barrages (reservoirs) are located in depth; scarped valleys have less water than open ones; isolated mountains present a radial drainage pattern; plains may be seen by analyzing
Figure 1.—LANDSAT image E-3333-10421

1 Area of study in Central Western Spain
2 Bejar Corridor
land use (cereal cultivated dry land); forests and snow covered zones, and very dissected land, identify highest mountains, etc.

Photointerpretation of LANDSAT image E-2333-10241, taken December 21, 1975 shows the planation surface of Las Hurdes as easily recognized. Morphostructural lines are also pointed out, so, weakness lines which have depressed Bejar Corridor, a voussoir between Sierra de Gredos and Las Hurdes, are the most often appearing NE-SW faults. They follow the same direction as the Jerte-Aravelle fault, and are responsible for the general alignment of mountains in this area: Sierra de las Mesas, de la Cachera, de Francia, are all block-mountains, elevated by alpine efforts. Locally, the contact between high Tertiary sediments of the Duero Basin and Paleozoic socle follows the same orientation. Tectonic "grabens" filled by Tertiary rocks (Moraleja, Coria, Ambroz, Ciudad Rodrigo Basins) are good examples. It would be interesting to research why "raña" type sediments (polymyctic quartzitic gravel-red clay conglomerate of pliocenic-villafranchian age) occupy the Ciudad Rodrigo - Salamanca Basin.

In the surroundings of Jerte fault many different little fractures were localized. Snow cover does not allow further investigation. Long NW-SE lines are only visible on satellite images, because conventional air photographs do not show them. Wrench faults in NNW-SSE direction were also recognized. E-W faults appear mostly in the southern part of image and belong to the "so called" Structural Band of Toledo. This alignments close some Miocene basins, so that alpine age is sure.

"Layer lines" are only visible when corresponding to quartzitic serpentines and "hardlings" (inselberge).

Hydrographic network analysis is also possible in the images. Encasement is visible as a shadowish company of water courses.
The estremenian and salmántinian peneplains are recognized by means of the superimposed rivers. Panglomarats of "raña" type look like alluvial fans at the "bajadas" of endorheic basins of Southwestern USA. An arid climate did reign when raña formations were laid.

Bands 5 and 6 are best for the recognition of granitic batholith, like the Garrovillas one, which occupies the Central Southern edge of image. Bands 6 and 7 are best for geomorphological exploring.
APPLICATION OF LANDSAT-2 DATA TO LAND USE MAPPING IN CENTRAL SPAIN.

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APPLICATION OF LANDSAT-2 DATA TO LAND USE MAPPING IN CENTRAL SPAIN.

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1. INTRODUCTION

Two land use maps of an area covering the province of Madrid, (around 8,000 km²) have been designed from LANDSAT images. Map 1 has been set up after analysis of black and white photographs (scale 1:500,000), but map 2 is a result of recording false color images (scale 1:250,000). Different transparencies (scale 1:1,000,000) of the province of Madrid, have been also taken into account. Analytic phase has been made with photographs at scale 1:500,000 and 1:250,000. Images at 1:500,000 were taken on July 10, 1975; July 11, 1975; July 28, 1975; July 29, 1975; September 2, 1975 and January 24, 1976, in bands 4, 5, 6 and 7. While false color images from March, 8 and 9, 1973 (scale 1:250,000) were only available to be used.

Analysis and interpretation were aided by light tables stereoscopes and magnifying glasses. Conventional air photographs 1956 (scale around 1:33,000) and 1972 (scale 1:15,000) have also been observed, and land use mapping of a 2,000 km² area, North of Madrid, was also discussed (Second Quarterly Report).

2. METHODOLOGY

First step was the election of a pilot zone from which it was possible to have, on one hand, satellite images and, on the other,
important and complementary information. The elected region lies over a surface of 2,000 km². Appearance of the highest number of significant land use units was imagined in it. This idea was soon verified (figure 1).

From satellite images, conventional airphotographs, available land use maps and specially with the support of direct field observations, a key for land use was elaborated for analysing the land use in the whole province. The key was directly verified on the spot. With this verification, a great number of problems were shown by LANDSAT. These problems will be analyzed later on.

Once with the key and in spite of the photointerpretative difficulties, we proceeded to analyze the rest of the territory confronting different forms of land use appeared, with those ready examined in the pilot area. Finally a later verification was made along chosen ways through the province to confirm the problems shown in the previous inform, and to evaluate the images from LANDSAT in the analysis of land use.

After comparing the black and white photographs, it is considered that for detection of the green cover and culture, bands 4 and 5 give better resolution to the images, and band 5 is the one from which the best results were obtained. Map number 1 has been elaborated from their photointerpretation. Bands 6 and 7 are not ready prepared for our purposes. This is the reason why they have not been used in this work, as the lithological units, tectonic lines and fluvial currents are more clearly shown in spite of their interesting and important notes and observations.
Figure 1.—Selected pilot area for land use classification of Madrid province.
3. RESULTS

In a country like Spain, where present land use forms are result of the influence of favorable and adverse conditions of surroundings, and of the modifications suffered through the history, to analyze satellite images is difficult, because for a detailed study is needed the scale 1:50,000 or 1:25,000. Therefore, these complex reasons do not advise LANDSAT images as the only document to elaborate thematic cartography, since there might be notable errors. It can be pointed out, however, that if auxiliary methods are used, as it was verified in the pilot area 2,000 km$^2$ analysed; the errors can be reduced to the minimum, while they are alarmingly increasing in the areas photointerpreted by means of selection and comparison.

The images of the satellite have been a very useful way to elaborate quickly maps of land use of provincial and regional groups; much more time would be required with conventional methods to elaborate the synthesis of a province or region. The great quantity of information gathered by the photographs of the satellite is a very important fact when it has to be interpreted the thematic map of land use, as this allows to establish important correlations of the land use with other geographic aspects (forms of relief, structural lines, lithology, etc.). On the other hand, as large stretches of land are shown on each photograph they permit to reach the study of regional geographic groups. On the LANDSAT images of central region, in black and white as well as in colour, it can be distinguished clearly, and with a highly trustworthy index, the following group of land use units:

- Coniferae forest
- Perennial leaf forests (evergreen-oak grove, plantations of juniper trees).
- Dry cereals farming
- Intensive watering
- Big nucleus of population
- Dams

The false colour images of the area at 1:250,000 scale, offer more possibilities than the black and white ones, in the detection of medium and small nucleus of population, as well as in the identification of communications; while it gives imprecisions in some types of forest limits in relation with the black and white photogram.

4. ANALYSIS OF THE GENERAL PROBLEM

The problems come from various types of facts; one of the most important is that the characteristic photographic images in false colour, as well as in black and white, obstructs the stereoscopic sight, except for a small sector, and this makes impossible to appreciate relief, which has a great influence in detecting unities of uncertain use. In the same way, the structure shown by photographs makes difficult to get: satisfactory images on the enlargements made through magnifying lenses.

The photographs also state problems at scales 1:500,000 and 1:250,000, as it is impossible to show some of the ways of using the land which conjugate their scarce superficial extent with their high economical output, such as the intensive local watering.

A very important fact in the interpretation of photographs is the date when images have been taken in the analysis of land use. On the images taken between July and September, the
contrasts are better defined, whilst in January and March the tonalities are in general blurred, and this makes the analytic work enormously difficult, as the Atlantic forests tend to get mixed with bushed and pasture grounds fenced-in by trees, and the little intensively irrigated lands get similar to some dry lands.

Bush-trees growing (oliveyard an vineyard) are the ways of land use impossible to recognise, on the black and white photographs at scale 1:500.000 as well as on the false-colour ones at scale 1:250.000, because they appear as small parcels and formations of various kinds.

Bushed can be easily mistaken with atlantic forest, with pasture lands fenced-in and with some of the uncultivated lands.

Non-fenced meadows can have tonalities similar to some of the uncultivated lands. In the same way, it is impossible to separate species inside each formation, in the coniferae as well as in the other types of forest; however, under certain conditions the recently reforested masses, can be distinguished provided they occupy a considerable surficial extent.

Little intensively irrigated lands are detected if the date when the photograph has been taken is between July and September.
REMOTE SENSING TECHNIQUES

REMOTE SENSING TECHNIQUES APPLIED IN A MULTISPECTRAL SURVEY OF ARANJUEZ TEST SITE.

Germán Lemos (*), Javier Salinas (**) and Manuel Rebollo (***)

(*) Remote Sensing Laboratory
Geographic and Cadastral Institute.

(**) Service of Photogrammetry and Photointerpretation
Polytechnic University of Madrid.

(*** IBM-Scientific Center
Autonomous University of Madrid.
REMOTE SENSING TECHNIQUES

REMOTE SENSING TECHNIQUES APPLIED IN A MULTISPECTRAL SURVEY OF ARANJUEZ TEST SITE.

By Germán L. Lemos (*), Javier Salinas (**) and Manuel Rebollo (***)

1. OBJECTIVES

As part of this NASA supported project, the Remote Sensing Laboratory of Instituto Geográfico y Catastral has participated in a survey of Aranjuez test-site, with the purpose of obtaining, by means of remote sensing techniques, basic data to work with in a multidisciplinary approach. The pilot area of Aranjuez is located South of Madrid (figure 1), and it has a rectangular shape of 7 km x 14 km.

The survey was conducted at three different stages. In a first stage, field works were done for acquisition of ground truth in the pilot area, with the idea of correlating such information to the data obtained, in a second stage, by means of an airborne multispectral scanner and photographic cameras. In a third stage it was analyzed the best existing LANDSAT information over the area for the purpose of defining how it would correlate to the data obtained during the aerial mission. The ground data and the aerial information were obtained simultaneously, while LANDSAT information available for analysis corresponded to an image dated several months before the date of flight.

As intention of this operation it was defined the development of methods and techniques for acquisition of data with remote

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(**) Servicio de Fotogrametría y Fotointerpretación. Universidad Politécnica de Madrid.

(***) Centro de Investigación UAM-IBM. Universidad Autónoma de Madrid.
Figure 1 — Pilot area of Aranjuez as it is seen in LANDSAT image
sensors, in a mode which was relatively new to Spanish investigators. As secondary objective it was defined the analysis and scientific application of the information in several disciplines. As part of this secondary objective, it was intended the correlation of LANDSAT and airborne MSS data over the test site. Figure 2 shows the topographic configuration of the pilot area at approximate scale 1:50,000, with the position of sites where local measurements have been done, and the directions of flight. The aerial mission was conducted in May 15, 1976 under good atmospheric conditions.

2. GROUND SEGMENT

The area of Aranjuez was chosen as test site for the following reasons:

1 - it is included in the area of Central Spain under study for this NASA supported project, and both photographic and digital LANDSAT data exist on it. Another important reason for selecting such test site, which has to be taken into account in a country like Spain, is that Aranjuez is not subject to limitations in flight imposed by the military organizations, nor it is included in any commercial air traffic corridor. Although LANDSAT satellites provide digital data over any area of the country, freely distributed all over the world, when planning a civil aerial mission in Spain there are military restricted areas which cannot be flown. Such situation was avoided in the case of Aranjuez.

2 - the test site presents a land use very clearly defined, with differentiation of urban areas, crops, bare soils and three rivers. At the edges are located the city of Aranjuez and the village of Titulcia, where some archeological deposits have been found.
Figure 2.—Topographic map of Aranjuez pilot area with location of sites were ground truth was obtained
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Tajo river</th>
<th>Jarama river</th>
<th>Confluence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site no. 1</td>
<td>Site no. 3</td>
<td>Site no. 6</td>
<td>Site no. 5</td>
</tr>
<tr>
<td>Turbidity</td>
<td>F.T.U.</td>
<td>8</td>
<td>8</td>
<td>110</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>mg/l.</td>
<td>7</td>
<td>6</td>
<td>119</td>
</tr>
<tr>
<td>Dry residual</td>
<td>(110°C) mg/l.</td>
<td>965</td>
<td>943</td>
<td>573</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.35</td>
<td>7.40</td>
<td>7.05</td>
</tr>
<tr>
<td>Conductivity</td>
<td>(25°C) mg/l.</td>
<td>1260</td>
<td>1276</td>
<td>1050</td>
</tr>
<tr>
<td>D.O.C.</td>
<td>mg/l.</td>
<td>22</td>
<td>18</td>
<td>146</td>
</tr>
<tr>
<td>Detergents A.B.S.</td>
<td>mg/l.</td>
<td>___</td>
<td>___</td>
<td>2.54</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/l. Cl⁻</td>
<td>70.8</td>
<td>61.9</td>
<td>79.6</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/l. SO₄²⁻</td>
<td>510</td>
<td>474</td>
<td>240</td>
</tr>
<tr>
<td>Carbonate</td>
<td>mg/l. CO₃²⁻</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>mg/l. CO₃H⁻</td>
<td>158.6</td>
<td>158.6</td>
<td>219.6</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/l. Ca²⁺</td>
<td>172</td>
<td>172</td>
<td>96</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/l. Mg²⁺</td>
<td>53.5</td>
<td>43.7</td>
<td>31.6</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/l. Na⁺</td>
<td>60</td>
<td>54</td>
<td>71.2</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/l. K⁺</td>
<td>2.1</td>
<td>2.2</td>
<td>14.7</td>
</tr>
</tbody>
</table>

Table 1.
3 - Tajo, Tajuña and Jarama rivers present in the pilot area a
very different physical pattern because their different
degree of pollution. From airborne MSS data it was expected
to differentiate the pure waters of Tajo and Tajuña rivers
and the polluted flow of Jarama, which receives on its upper
course the detritus of a large city like Madrid, 3 million
inhabitants.

4 - at the irrigation lands along Jarama, Tajo and Tajuña rivers,
an analysis of phenological states of crops could be possible
if the area flown at low altitudes, being interesting to
find out differences in the reflectance of cereals, olive-
groves and bare soils of gypsum.

Aranjuez offered good conditions for flight at low altitude,
with a maximum spot height of 642 m in Valdelascasas vertex.
Furthermore, a rapid access by highway is guaranteed from Madrid
in 45 minutes, and the transportation network into the pilot
area is in good conditions. The terrain is formed by gypsums,
silty loams and lacustrine limestones. As vegetation, broad
areas are cultivated along the irrigated lands of Jarama, Tajo
and Tajuña rivers, while the rest of the zone has olive-groves
or bare soils. In figure 3 it is presented a panoramic view of
the test site with the city of Aranjuez in first term.

As part of the ground survey it was done photointerpretation
work by experienced personnel of Instituto Nacional de Investi-
gaciones Agrarias in sites no.10 and 12, mainly focused to the
identification of different types of crops. Also, around the
city of Titulcia black and white infrared images were taken
for the purpose of identifying archeological sites (number 8
in figure 2).

Multiband photography was also tested during the day of flight
in sites no.1, 2 and 11 (figure 2), with Minolta cameras and
Figure 3.—Panoramic view of the pilot area with the city of Aranjuez in first term

Figure 4.—Bandpass Wratten filter combinations tested
DIRECCION GENERAL DEL INSTITUTO GEOGRÁFICO Y CATASTRAL

LABORATORIO DE TELEDETECCIÓN

FOTOGRAFÍA MULTIBANDA

LOCALIDAD ARANJUEZ
LUGAR FINCA INIA SOTOMAYOR
MOTIVO VUELO MSS
FECHA 15 – MAYO – 1976

HORA SOLAR; 10'45 – 11'30
PELÍCULA PANATOMIC
CAMARA MINOLTA
SENSIBILIDAD 32 ASA

CIELO □ DESPEJADO □ POCO NUBOSO □ CUBIERTO

DATOS FOTOGRAFÍCOS

<table>
<thead>
<tr>
<th>N°</th>
<th>FOCAL (mm.)</th>
<th>DIÁFRAGMA</th>
<th>EXPOSICIÓN (1/seg)</th>
<th>FILTRO</th>
<th>OBSERVACIONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>8 - 11</td>
<td>125</td>
<td></td>
<td>panorámica</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>8</td>
<td>125</td>
<td>polariz.</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>1'4 - 2'8</td>
<td>60</td>
<td>18A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>4 - 5</td>
<td>60</td>
<td>47B</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>5'6</td>
<td>60</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&quot;</td>
<td>4 - 5</td>
<td>60</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>&quot;</td>
<td>5'6</td>
<td>30</td>
<td>47B + 3</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>&quot;</td>
<td>2'8</td>
<td>60</td>
<td>4 + 48</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>&quot;</td>
<td>2'8</td>
<td>60</td>
<td>2E + 48</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>1'4 - 2'8</td>
<td>60</td>
<td>45 + 57</td>
<td></td>
</tr>
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<td>11</td>
<td>&quot;</td>
<td>2'8</td>
<td>60</td>
<td>4A + 61</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>&quot;</td>
<td>4</td>
<td>60</td>
<td>16 + 64</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>&quot;</td>
<td>4</td>
<td>60</td>
<td>21 + 57</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>&quot;</td>
<td>2'8</td>
<td>60</td>
<td>23 + 57</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>&quot;</td>
<td>4</td>
<td>30</td>
<td>72B</td>
<td></td>
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<tr>
<td>16</td>
<td>&quot;</td>
<td>4</td>
<td>15</td>
<td>29 + 72B</td>
<td>no se ve el fotómetro</td>
</tr>
<tr>
<td>17</td>
<td>&quot;</td>
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<td>60</td>
<td>61</td>
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<tr>
<td>18</td>
<td>&quot;</td>
<td>1'4 - 2'8</td>
<td>60</td>
<td>61 + 25</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EL OBSERVADOR,

Figure 5. Sheet of the survey book filled during field work in site no 12, called "finca INIA Sotomayor".
several film-filter combinations. The filters used were Wratten and BDB, while the films tested in the ground have been the following:
- Panatomic
- Plus-X Pan

Figure 4 shows the filter combinations tested for the purpose of obtaining narrow bandpasses of sun reflected radiation. Such single or double combinations have been tried as assay of future multiband missions, and for selection of the best bands to be used in each application. Figure 5 represents one sheet of the survey book filled during the field work at site no.12, called "finca INIA Sotomayor".

Simultaneously to the aerial flight, local measurements have been done of physical parameters in the ground for determining atmospheric conditions and chemical components of the water. Samples of Tajo and Tajuña rivers were taken and analyzed by the Laboratory of Water Analysis of the Center of Hydrographic Studies, in sites no.1, 3, 4, 5 and 6. Figure 6 corresponds to site no.3 in Tajo river, while figure 7 was taken in site no.7.

In table 1 is enclosed the result of the analysis of water samples.

As ancillary information for acquisition of ground truth in the test site have been used topographic maps at scale 1:50.000, geological and forestry charts at scale 1:400.000, and the Lithologic Map of Spain. Aranjuez is located in the sheet no. 605 of the National Topographic Map at scale 1:50.000.

3. AERIAL SEGMENT

The aerial survey was conducted by Instituto Nacional de Técnica Aeroespacial in an airplane CASA-212 (figures 8 and 9)
Figure 6. Obtaining water samples in Tajo river (site no 3)

Figure 7. Partial view of Tajo river on its pass by the city of Aranjuez (site no 7)
equipped with the following sensors:
- 4 Hasselblad cameras 500 EL, f/50
- multispectral scanner Daedalus, 10 channels

The cameras were loaded with the following films and filters:
- Panatomic-X 3410 Wratten 58
- Panatomic-X 3410 Wratten 47B
- Aerochrome IR 2443 Wratten 12
- Kodak black and white IR 2424 Wratten 88.

The scanner did not operate in thermal IR wavelengths, being the bands used indicated in table 2. The MSS Daedalus was available

<table>
<thead>
<tr>
<th>channel</th>
<th>spectral band ((\mu))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.38 - 0.42</td>
</tr>
<tr>
<td>2</td>
<td>0.42 - 0.45</td>
</tr>
<tr>
<td>3</td>
<td>0.45 - 0.50</td>
</tr>
<tr>
<td>4</td>
<td>0.50 - 0.55</td>
</tr>
<tr>
<td>5</td>
<td>0.55 - 0.60</td>
</tr>
<tr>
<td>6</td>
<td>0.60 - 0.65</td>
</tr>
<tr>
<td>7</td>
<td>0.65 - 0.70</td>
</tr>
<tr>
<td>8</td>
<td>0.70 - 0.80</td>
</tr>
<tr>
<td>9</td>
<td>0.80 - 0.90</td>
</tr>
<tr>
<td>10</td>
<td>0.90 - 1.10</td>
</tr>
</tbody>
</table>

Table 2. MSS Daedalus spectral bands.

from the French CNES (Centre National d'Etudes Spatiales), who supplied the equipment, technical personnel and preprocessing of the information for this survey, as part of the Scientific and Technical Cooperation Agreement signed between France and Spain.
Figure 8.—Airplane CASA-212 used in the multispectral survey.

Figure 9.—Interior view of a CASA-212 airplane equipped for aerial photography missions at the Cartographic and Photographic Service of the Air Force.
The MSS Daedalus has the following components:
- optical head of scanning in two channels
- array of multispectral detection in the visible
- electronic console of command and control
- distribution box
- control unit of sources of reference
- system of visualization

The optical head of scanning is composed by a rotating mirror, parabolic optics, dichroic plate for selection of visible or IR radiation, two lamp sources of references and a gyroscopic system of movement compensation. Its major characteristics are indicated in table 3.

<table>
<thead>
<tr>
<th>Optical head of scanning</th>
<th>characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral band</td>
<td>0.38 - 1.1 μ</td>
</tr>
<tr>
<td>Total FOV (geometric)</td>
<td>87° 20'</td>
</tr>
<tr>
<td>Scanning rate</td>
<td>80 rps (fixed)</td>
</tr>
<tr>
<td>Instantaneous FOV</td>
<td>2.5 mrd.</td>
</tr>
</tbody>
</table>

Table 3.

Both sources of reference are lamps calibrated at the N.B.S. (National Bureau of Standards), giving two squared signals just before and after the video signal obtained from the earth radiation in each rotation of the scanning mirror (figure 10).

Figure 10. Complex video signal.
Figure 11.—Color infrared image obtained with Hasselblad camera on site no. 10 (original in 70 mm format)
Figure 12 — Photointerpretation of the image shown in figure 11
Calibration lamps give signals of amplitudes, corresponding to the lower and higher video signals received from the earth, whose equivalent spectral radiance is represented by a term \( L_i \) in each channel.

Besides the recording of multispectral information in analog tape, visualization was obtained on negative film for each channel by a cathode tube of optical fibers. A correction in tangency removed the image distortion. Also, analog information was converted to digital in channels 2 to 10 and recorded by CNES at Toulouse.

Scanning along cross-track direction was recorded at 512 points per line coded in binary mode at 8 bits, representing in each pixel the amplitude of the signal value once calibrated. Such calibrated amplitudes were obtained for the mean values of the positive and negative reference sources in each line and in the 9 former lines, according to the following formula for each visible channel \( i \):

\[
\text{VAL}_\text{calibrated} = C_i \frac{\text{VAL}_{\text{bulk}} - R^-}{R^+ - R^-} 
\]

where,

- \( \text{VAL}_{\text{bulk}} \) = bulk value of digitized amplitude
- \( R^+ \) = mean of positive amplitudes of calibration in 10 lines
- \( R^- \) = mean of negative amplitudes of calibration in 10 lines
- \( C_i \) = associated factor to each channel allowing a coding of amplitudes in the dynamic range 0-255

In every channel the factor \( C_i \) had a value of:

\[
C_i = L_i \times K_i \quad (\text{mW}/(\text{cm}^2 \cdot \mu\text{sr}))
\]

where \( L_i \) represents the above mentioned spectral radiance and \( K_i \) is a coefficient which divides the amplitudes for obtaining physical values. The coefficients \( K_i \) are available on tape at the beginning of each scene, being different for each channel.
Figure 13.—Black and white image obtained over the confluence of Tajo (lower part) and Jarama (right) rivers. Point indicate densitometric analysis done on the original negative.
In the case of Aranjuez test site their value is indicated in table 4.

<table>
<thead>
<tr>
<th>channel</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_i$</td>
<td>23.2</td>
<td>15.7</td>
<td>15.1</td>
<td>14.9</td>
<td>16.9</td>
<td>17</td>
<td>20.9</td>
<td>24.8</td>
<td>32.1</td>
</tr>
</tbody>
</table>

Table 4.

As it can be seen from (1), the "history" of the recorded earth radiation is taken into consideration and the value of pixel amplitudes has a relative significance in each channel, although it is not correlated in different channels.

The aerial mission was conducted on May 15, 1976 at 500 m height with a nominal speed of 54 m/s. The direction of each pass over the test site is indicated in figure 2.

The color IR images obtained with the Hasselblad cameras have allowed a rapid work of photointerpretation based on the existing field data. Because the low height flying altitude, most of the surficial features have been easily identified without ground control. This applies namely to the recognition of different types of crops, which is being carried out, at the date of submission of this final report, by the Service of Photogrammetry and Photointerpretation of the Polytechnic University of Madrid. In figure 11 is shown as example an enlarged image obtained in false color during the aerial mission, while figure 12 represents its photointerpretation.

Black and white multiband photography has also provided valuable data in the analysis of water pollution at Jarama river. Figure 13 represents one of the images obtained over the confluence of Tajo and Jarama rivers (site no.5), with indication of the points where densitometric analysis have been effected on the original
Figure 14.—Photographic recording of a digitized scene obtained by the MSS Daedalus over Titulcia in site no. 8 (Courtesy of CNES)
Figure 15.—Photointerpretation of the image shown in figure 14
negative. The filter used in this scene was the Wratten 47B.
Measurement of optical densities was done on a Welch densitometer by transparency, with the results indicated in Table 5.

<table>
<thead>
<tr>
<th>Point</th>
<th>1T</th>
<th>2T</th>
<th>1J</th>
<th>2J</th>
<th>1C</th>
<th>2C</th>
<th>3C</th>
<th>4C</th>
<th>5C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.24</td>
<td>0.26</td>
<td>0.36</td>
<td>0.42</td>
<td>0.36</td>
<td>0.32</td>
<td>0.59</td>
<td>0.29</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 5.

Although digital processing of the MSS Daedalus magnetic tapes is undergoing at this moment in cooperation with the IBM-Scientific Center of the Autonomous University of Madrid, some good quality images have been furnished by the Mathematic Division of CNES in Toulouse. Figure 14 represents an enlarged copy of the film recording of digital data done in channel 9 over Titulcia (site no. 8). It can be seen on the image the village (upper right) and both Tajuña river (left) and the channel of Vega de Chinchón (center). In Figure 15 is shown the photointerpretation of Figure 14.

During the aerial mission it was avoided the influence of different sun angle elevations by conducting the flight at noon (12 a.m. to 2 p.m.), with a vertical incidence of light to the target and vertical reflectance of solar radiation detected by the scanner.

Processing of photographic films used with the Hasselblad cameras was done at the Remote Sensing Laboratory of Instituto Nacional de Técnica Aeroespacial, in Torrejón de Ardoz, Madrid.

4. SPACE SEGMENT

LANDSAT information was included in this survey as a tool for obtaining an automatic classification of land use in Aranjuez.
### Cluster Report Menu

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Population Match</th>
<th>Distance Match</th>
<th>Distance Name</th>
<th>Cancel</th>
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</thead>
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<td>0</td>
<td></td>
</tr>
<tr>
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<td>498</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td>760</td>
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<td>0</td>
<td></td>
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<td>0</td>
<td></td>
</tr>
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<td>10</td>
<td>287</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
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<td>0</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>42</td>
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<td>0</td>
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</tr>
<tr>
<td></td>
<td>172 UNRECOGNIZED P</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 16.—Cluster menu representing the population in each class

### Detailed Clustering Report

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
<th>Cluster 4</th>
<th>Cluster 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% from a</td>
<td>% from b</td>
<td>% from c</td>
<td>% from d</td>
<td>% from e</td>
</tr>
<tr>
<td>C (of)</td>
<td>MEAN</td>
<td>STD</td>
<td>MEAN</td>
<td>STD</td>
<td>MEAN</td>
</tr>
<tr>
<td>1</td>
<td>49.25</td>
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<td>1.67</td>
<td>36.73</td>
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<td>46.63</td>
<td>2.76</td>
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<td>2.09</td>
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<tr>
<td>3</td>
<td>47.14</td>
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<td>31.40</td>
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<tr>
<td>4</td>
<td>22.43</td>
<td>1.93</td>
<td>14.74</td>
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<td>19.59</td>
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</tbody>
</table>

Figure 17.—Mean and standard deviation values of cluster classes

Original page is of poor quality
### Detailed Clustering Report

<table>
<thead>
<tr>
<th>RUN</th>
<th>CLUSTER 6</th>
<th>CLUSTER 7</th>
<th>CLUSTER 8</th>
<th>CLUSTER 9</th>
<th>CLUSTER 10</th>
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<tr>
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<td>C FROM 0'0</td>
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<td>C FROM 0'0</td>
<td>C FROM 0'0</td>
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<tr>
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<td>S FROM 0</td>
<td>S FROM 0</td>
<td>S FROM 0</td>
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</tbody>
</table>

<table>
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<th>STD</th>
<th>MEAN</th>
<th>STD</th>
<th>MEAN</th>
<th>STD</th>
<th>MEAN</th>
<th>STD</th>
<th>MEAN</th>
<th>STD</th>
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</thead>
<tbody>
<tr>
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<td>59.49</td>
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<td>26.29</td>
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</tr>
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</tr>
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<td>3</td>
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<td>2.85</td>
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<td>12.62</td>
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<td>1.54</td>
<td>25.60</td>
<td>1.56</td>
<td>27.33</td>
<td>1.41</td>
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</table>

Figure 18.—Mean and standard deviation values of cluster classes

<table>
<thead>
<tr>
<th>RUN</th>
<th>CLUSTER 11</th>
<th>CLUSTER 12</th>
<th>CLUSTER 13</th>
<th>CLUSTER 14</th>
<th>CLUSTER 15</th>
</tr>
</thead>
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<td>C FROM 0'0</td>
<td>C FROM 0'0</td>
<td>C FROM 0'0</td>
</tr>
<tr>
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<td>S FROM 0</td>
<td>S FROM 0</td>
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<td>S FROM 0</td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>STD</th>
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<th>STD</th>
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<th>STD</th>
<th>MEAN</th>
<th>STD</th>
<th>MEAN</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.30</td>
<td>26.09</td>
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<td>24.72</td>
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<td>1.73</td>
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<tr>
<td>2</td>
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<td>1.87</td>
<td>23.98</td>
<td>2.61</td>
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<td>21.37</td>
<td>2.17</td>
<td>18.09</td>
<td>2.16</td>
</tr>
<tr>
<td>3</td>
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<td>2.19</td>
<td>31.91</td>
<td>2.52</td>
<td>25.64</td>
<td>2.33</td>
<td>20.94</td>
<td>2.15</td>
<td>52.76</td>
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<tr>
<td>4</td>
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<td>1.70</td>
<td>14.49</td>
<td>1.79</td>
<td>12.08</td>
<td>1.64</td>
<td>7.40</td>
<td>1.65</td>
<td>27.14</td>
<td>1.69</td>
</tr>
</tbody>
</table>

Figure 19.—Mean and standard deviation values of cluster classes

**ORIGINAL PAGE IS OF POOR QUALITY**
test-site. The aerial flight conducted at low altitude was intended to provide a knowledge of the area, which could be correlated and used for a supervised classification of resources in Aranjuez by means of LANDSAT MSS data.

As a first step in this program, which is undergoing now, a classification of LANDSAT image no. 2223-10135 was done by clustering techniques, assuming that none ground truth of the pilot area existed, in the intent of determining the capability of the satellite by itself for surveying Aranjuez land uses.

The cluster analysis was done at the IBM-Scientific Center of the Autonomous University of Madrid, where ERMAN-II program is available on an IBM 360/65 computer interfaced to an interactive television terminal RAMTEK. Such powerful software was used for classifying Aranjuez test site. The area represents on tape no. 2223-10135 a rectangle of 250x256 pixels, being the upper left corner of the subscene in line 1400 and pixel 1250.

Before any classification was done, a registration was conducted on the digital tapes for geometrically correcting the subscene and positioning it by reference to a grid in UTM projection. Such procedure has been explained in another section of this final report (reference 1). Coordinates of control points were extracted from the National Topographic Map at scale 1:50,000, published by Instituto Geográfico y Catastral (sheet no. 605).

After an accurate geometric correction was done, clustering of the subscene was intended with 15 classes and the same "a priori" probability P(Wi) for all of them. Figure 16 represents the population included in each class, and figures 17, 18 and 19 indicate the mean and standard deviation values obtained for each class of cluster. At this point, a plot was effected of
spectral radiance levels versus all four MSS channels for the 15 clustering classes (figure 20). Furthermore, the mean and standard deviation values of each of the 15 classes was represented in channels 2 (band 5 of LANDSAT MSS sensor) and 4 (band 7 of LANDSAT MSS sensor). Bands 5 and 7 have been selected for this plot because they show lower correlation of information than any other two bands of MSS sensor (this subject is discussed in another section of this final report - see Digital Processing - reference 2).

As result of this graphic representation, and because the existing similarities in spectral responses of classes, a grouping in 8 new classes was intended from the previous clustering classification. Table 6 summarized the reduction in classes carried out, with indication of the color assigned to the new grouping.

<table>
<thead>
<tr>
<th>GROUPING OF CLUSTERS</th>
<th>NEW CLASS</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>I</td>
<td>yellow</td>
</tr>
<tr>
<td>G - H</td>
<td>G</td>
<td>light green</td>
</tr>
<tr>
<td>A - E - B</td>
<td>A</td>
<td>cyan</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>blue</td>
</tr>
<tr>
<td>Q - N</td>
<td>Z</td>
<td>violet</td>
</tr>
<tr>
<td>F - J - L</td>
<td>Y</td>
<td>white</td>
</tr>
<tr>
<td>K - P</td>
<td>X</td>
<td>red</td>
</tr>
<tr>
<td>M</td>
<td>M</td>
<td>black</td>
</tr>
</tbody>
</table>

Table 6.

The result of this grouping of clusters in 8 new classes produced the image shown in figure 21; where one of the classes, corresponding to water, has been separately represented in figure 22.
5. RESULTS AND DISCUSSION

The survey of Aranjuez test site has allowed to the participant organizations in this project an acquisition of know how and apprenticeship in remote sensing techniques applied to several disciplines which promises good result in the future when more systematic surveys of the country will be conducted. This is probably the most important accomplishment that the multidisciplinary survey has produced in all participants.

As part of the field work conducted in Aranjuez it is here dedicated a comment to both types of films tested, Panatomic (32 ASA) and Plus-X Pan (125 ASA).

Although the higher sensitivity of Plus-X Pan film, when an aerial mission is conducted there is in general a need for a good speed photographic film with high resolution. Such requirements are better satisfied by the Panatomic film. In the field, when the camera is mounted on tripod and focused to a fixed objective, being the time of exposure not critical and able to increase as much as needed, Panatomic film provides better results than Plus-X Pan film. This has been observed in Aranjuez, in spite of the better sensitivity of Plus-X Pan film.

The film-filter combinations tested have provided more details and a better contrast of the images when used Panatomic film. As it can be seen in digures 4 and 5, several filters were tested in an effort to select the best spectral bands to be used for each general application. Although results show very similar and none comment can be done until the spectral curves of objectives are determined, some combinations of Wratten filters are rejected because their low transmission of light in the spectral region where film used is sensitive. Such rejected combinations are the following:
Figure 20.—Spectral radiance levels in LANDSAT MSS bands (right), and mean-standard deviation values of each cluster class in MSS bands 5 and 7 left.
Better results were obtained with the conventional filters used in multiband aerial photography:

- 47 B (360 nm - 500 nm)
- 58 (465 nm - 620 nm)
- 25 (580 nm - limit of film sensitivity)

From the analysis of water samples taken in Jarama and Tajo rivers (table 1 - sites 1, 3, 4, 5 and 6 of figure 2), it can be stated the high content of suspended solids and turbidity of Jarama waters, with a D.Q.O. value of 146 mg/l oxygen. The densitometric analysis of waters in the confluence of Jarama and Tajo rivers (figure 13 - Table 5), shows that a certain correlation exists between optical densities in the film versus turbidity and suspended solids in the waters. These two physical parameters can be clearly identified on the aerial imagery in a qualitative mode. Points 3C and 4C do not seem representative because the presence of foams on them and the existence of backwaters. Although some other chemical components of the waters could be correlated to the optical densities measured, it seems that the spectral response produced by turbid waters is much more strong than the one detectable from chemical pollutants.

The photointerpretation work conducted for identification of different types of crops and phenological states has shown the uniqueness of color infrared aerial photography for these purposes when taken at low altitudes. As example, it can be seen in figure 11 and on its interpretation (figure 12), that photointerpretation of different types of crops is an easy and economic way of work. As result of this survey a comparison has been done of the cost of photointerpretation and field
work, based on an aerial flight at mean scale 1:7,000 (table 7). It can be deduced from the table the economy and convenience that represents to work by means of photointerpretation techniques in Aranjuez test site.

Agronomic photointerpretation results difficult from the information supplied by the MSS Daedalus, once converted to black and white images. As it is shown in figures 14 and 15 different types of crops have a very similar gray tonality, even if densities are controled during the print out process. However, by digital analysis of the data and false color combination of different bands, results could be improved, although the cost of computer processing could never be competitive with the photointerpretation of color IR imagery.

In the analysis of LANDSAT data done by clustering techniques it has been determined that the satellite by itself (without ground support) was not able to discriminate the existing types of land uses in Aranjuez. The identification of cluster classes showed extremely difficult and none result can be anticipated. As example it is indicated here what every grouped spectral class could be, without reasonable possibility of determining their real content (table 8).

From table 8 it was deduced by photointerpreters that the different colors appearing in the images when due to various types of soils had the influence of moisture, erosion, land uses, etc. Even in cases where the identification and location of a pattern was possible, the low extension of parcels in Aranjuez produces a mixed spectral response in every LANDSAT MSS pixel which does not allow any accurate automatic classification. Results could probably be improved when a supervised classification was done based on well known training fields. Such training fields could be selected based not in
Field work

In Aranjuez with aerial photograms at scale 1:7000 including displacements and the later work in cabinet:

- Hectares photoidentified per person and day = 270
- Cost of displacements: 150 Km. at 8 pts/Km. = 1,200
- Diets = 500
- Salary = 1,000
  \[ \text{Total} = 2,700 \]

Price per hectare photoidentified = 10 pts./Ha.

Photointerpretation

In the same area and the same conditions of imagery:

Price per hectare photointerpreted = 6 pts/Ha.

Table 7. Cost analysis of field work and photointerpretation in Aranjuez test site.

<table>
<thead>
<tr>
<th>Cluster class</th>
<th>Possibility in the ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>black</td>
<td>water, terrains with moisture</td>
</tr>
<tr>
<td>light green</td>
<td>crops in alluvial soils (dry and irrigated)</td>
</tr>
<tr>
<td>cyan</td>
<td>dry farming crops, pastures, scarce vegetative cover, bare soils</td>
</tr>
<tr>
<td>violet</td>
<td>scrubs, humid areas</td>
</tr>
<tr>
<td>red</td>
<td>scrubs, olive-groves</td>
</tr>
<tr>
<td>yellow</td>
<td>irrigation lands, not alluvial terrains</td>
</tr>
<tr>
<td>blue</td>
<td>dry farming crops, olive-groves, residential areas, industrial and urban land use</td>
</tr>
<tr>
<td>white</td>
<td>not identified</td>
</tr>
</tbody>
</table>

Table 8. Possibilities of identification in the 8 classes cluster run on LANDSAT tape over Aranjuez pilot area.
Figure 21. — Color representation of 8 cluster classes obtained by digital analysis of LANDSAT data.
Figure 22.—Cluster class corresponding to water in Aranjuez test site, showing Jarama and Tajo rivers
the existing information on the ground, but by means of the aerial images taken during the survey at low altitude, namely false color photography. Once the images photointerpreted, their content of information should allow a very accurate definition of training fields through the RAMTEK TV terminal. Furthermore, the higher resolution of the images should guarantee a correct location of training fields, increasing the accuracy in selecting their corresponding pixel(s) on the LANDSAT image, or even their position into the pixel. This transfer of data from the aerial segment to the space segment should probably need an intermediate step in the form of aerial images at small scale (1:60,000 or similar), for carrying out a generalization of information, which appears necessary because the low resolution of the MSS pixel (80x80 m on the ground).

Another limiting factor in the malfunction of the cluster has been the different date of observation with the satellite and with the airplane, although it does not seem critical in the case of Aranjuez.

The strongest limitation to the application of LANDSAT data in Aranjuez, and this is an example of what has been happening along this project in Central Spain, comes from the small size of the parcels, which is not appropriate to the already low resolution of the MSS sensor. As example of this it was shown in figure 22 the cluster corresponding to water. It might represent the course of Jarama river (diagonal in the image) and the Tajo also (horizontal in the lower part of the image), but because the reduced width of Tajo river on its pass by Aranjuez, which does not surpass 40 m (half of a LANDSAT pixel), it presents a discontinuity. Another reason for such discontinuity is the vegetative cover along Tajo margins, with numerous trees of powerful crowns. Such situation is well represented in figures 6 and 7.
Finally, although in the water class obtained by cluster Jarama river is represented in black color (figure 22), this does not mean that Tajo waters "are not black". In fact, the satellite detects Tajo river as "more black" than Jarama in the IR region, and this is due to the strong pollution of the last, which produces its higher reflectance and its better detection by MSS sensor in band 7. Because the purity of Tajo waters, their absorption of sun radiation is stronger in the infrared band than Jarama waters, which reflect more light due to the presence of surface pollutants (turbidity and suspended solids concentration are good indicators of the spectral response produced).

From the archeological point of view good results have been achieved in the area. Around the village of Titulcia (sites no. 8 and 9) existed in earlier times a celtiberian burying-ground, another one visigothic, and a roman village. As Titulcia was an important point of communications during the roman times, two causeways had their crossing on the village; one going from Toledo to Segovia and the other from Mérida to Zaragoza.

At the time of submission of this final report several archeological sites have been detected, although their real nature cannot be stated until checking work in the ground will be carried out. The location of such sites is positioned around the arrow indicated in figure 2. The Instituto Español de Arqueología Rodrigo Caro is doing the basic research on the ground for determining whether or not an excavation might be conducted.
Aknowledgements

Aknowledgement is given to José Remesal, of Instituto Español de Arqueología Rodrigo Caro, who conducted the archeological recognition of Titulcia.

The cooperation of Dr. García de Nicolas, of Centre de Estudios Hidrográficos, is appreciated for his support in the acquisition of water samples and their analysis in laboratory. It is also recognized the collaboration of Dr. J. Manuel Varela, of Centro de Estudios Hidrográficos, who conducted basic work in the acquisition of ground truth.

The field survey carried out by Dr. Mario Nieves, of Instituto Nacional de Investigaciones Agrarias, is appreciated.

Aknowledgement is given to all personnel of the Department of Avionics and Electro-optics, of Instituto National de Técnica Aeroespacial, for their dedication to this project and their valuable collaboration.

The participation of the Air Photographic Squadron 403 of Servicio Cartográfico y Fotográfico del Aire, whose pilots conducted this aerial survey, is greatly acknowledged.

References


WATER RESOURCES

APPLICATION OF LANDSAT-2 DATA TO HYDROLOGY IN CENTRAL SPAIN

Center of Hydrographic Studies
Ministry of Public Works
Madrid
SPAIN.
WATER RESOURCES

APPLICATION OF LANDSAT-2 DATA TO HYDROLOGY IN CENTRAL SPAIN.

By Centro de Estudios Hidrográficos
Ministerio de Obras Públicas
Madrid.

1. INTRODUCTION

As it was stated in the Second Quarterly Report the Centro de Estudios Hidrográficos (C.E.H.) intends to obtain from LANDSAT images useful information on the physical pattern of hydrographic basins from a synoptic point of view and taking into account their evolutive processes.

C.E.H. is in charge of the hydrologic studies and hydraulic acting in the national territory, through the divisions in hydrographic basins of the main rivers and their tributaries. Since many years ago it has inventoried such streams, delimited their basins and measured the length of the currents and the surface of the basins. Furthermore, the Center has determined the discharges of the rivers and the rainfall of the basins, through the corresponding hydrologic network of measurement. However, such quantitative data can be enriched with other qualitative information which, at synoptic scale, can be obtained from satellite images when supported by local measurements of "ground truth" and conventional methods of photointerpretation.

With this purpose, the C.E.H. intended to obtain information on the satellite images focused to:
- a more detailed delineation of drainage networks at synoptic scales (1:200,000 and 1:500,000).

- a classification of the terrain surface in hydrographic basins.

These two objectives can contribute to define criteria for the study of runoff in basins and sub-basins, because they provide parameters which are tied to it and which will be used for establishing mathematical models of simulation in the different basins.

In our earlier report it was intended to expand this study to all Central Region of Spain, as it was proposed in this multidisciplinary project. For reasons of urgency in the elaboration of this final report, as well as because the scarce number of hours-men dedicated to it, the area of analysis was restricted to only one hydrographic basin; in Guadarrama river, tributary of the Tajo on its right margin. This study will be expanded in the future to other areas when the techniques of analysis will be better known and when more spatial information will be available.

This study was conducted in four different fronts:
- drainage network
- geology
- vegetation
- farming

In the analysis of drainage network, treatment of the information was done with the support of D. Luis Montoto, of IBM-Scientific Center, Autonomous University of Madrid. The hydrographic interpretation was conducted by D. Jesús Paredes, of C.E.H.

Geology study had the cooperation of D. Manuel Esteras, of C.E.H.
Fig. 1.—False color image of Gaudarrama basin at scale 1:500,000 with location of training fields introduced to RAMTEK terminal

M. Timbered
D. Untimbered
Vegetation analysis was directed by D. Javier Luján, in collaboration with D. Carlos Notario and D.J. Antonio García Sánchez, all of them from C.E.H.

The group was coordinated by D. Jesús Cirugeda, and conjunction of these individual works was carried out by D. Jesús Paredes. The C.E.H. is directed by D. José María Martín Mendiluce, assisted by D. Rafael Heras.

2. TECHNIQUES

2.1. Available information

The following LANDSAT images received from NASA have been used in the works of interpretation:

<table>
<thead>
<tr>
<th>no.</th>
<th>identification</th>
<th>date</th>
<th>bands</th>
<th>support</th>
<th>tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1228-10325</td>
<td>8-3-73</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>1228-10325</td>
<td>8-3-73</td>
<td>F.C.</td>
<td>paper</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>2169-10145</td>
<td>10-7-75</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>2170-10204</td>
<td>11-7-75</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>2187-10143</td>
<td>28-7-75</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>2223-10135</td>
<td>2-9-75</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>2350-10182</td>
<td>7-1-76</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
<tr>
<td>8</td>
<td>2367-10122</td>
<td>24-1-76</td>
<td>4,5,6,7</td>
<td>paper</td>
<td>no</td>
</tr>
</tbody>
</table>

As ancillary information it was used:

- cartography 1:500,000 of Instituto Geográfico y Catastral (I.G.C.)
- maps of hydrographic basins at scale 1:50,000, based on the National Topographic Maps of I.G.C. at such scale.
- physical data of the basins in Spanish rivers (publication by C.E.H.)
- rainfall and flow metering data of the Hydrology Service of C.E.H.
Hydrographic network obtained from existing cartography at scale 1:500,000

GAGING STATIONS
- Flood prevention
- Scale and limnigraph
- Without limnigraph

METEOROLOGICAL STATIONS
- Thermometric
- Pluvimetric
- Complete station

Figure 2 — Image obtained by ratio of bands 5/7
Scale 1 : 500,000
- aerial photogrammetric flight (conducted by the Army Map Service in 1956-1957), at approximate scale 1:30,000.
- forestry map at scale 1:400,000 of the Ministry of Agriculture.

2.2. Treatment of the information

From the above mentioned images it was processed the no.2223-10135 tape for the purpose of obtaining:

- image with band ratio 5/7 at scale 1:500,000 including divisory lines of the basin and the sheets corresponding to the National Topographic Map at scale 1:50,000 (figures 2 and 3).
- false color image (4 = blue, 5 = green, 7 = red) at scale 1:500,000 (figure 1).

The geometric correction of the image was done by means of control points taken from the maps at scale 1:50,000. For this process, as it is explained in paragraph 3.1, it was used the following hardware:

- IBM 360/65 (1024K) computer
- RAMTEK GX 10013 interactive display system with CONRAC RHN19 Color TV screen
- Digital color image recorder DICOMED D-47

Digital data concerning to the divisory lines in the basins, and the limits of the sheets of the maps at scale 1:50,000 were introduced to the system by a digitizer DMAC with output on paper tape punch; being necessary to elaborate a program for conversion of the PEGASUS code to the code ASCII of IBM, by means of a computer NOVA of 32 K.

2.3. Hydrographic interpretation

For this interpretation it was used image no.6 in band ratio
Figure 3.—Image radiometrically corrected from figure 2. It is clearly identified the hydrographic network of Guadarrama river basin. Lines indicate borders of the 1:50 000 scale maps included in the basin.
5/7 at scale 1:500.000, completed with different black and white images, namely in band 7; being the results compared to the cartography of I.G.C. at scale 1:500.000.

2.4. Geologic interpretation

The geologic interpretation was done in priority on false color image no. 2, which was available in digital tape at scale 1:500.000, being also used the rest of images in black and white, namely in band 7. The interpretation was supported by the knowledge of the author, the existence of ground truth and the previous interpretation of conventional aerial images at scale 1:30.000.

2.5. Forestry interpretation

It was used for this purpose the RAMTEK terminal on image no. 6 for the selection of areas, evaluation of reflectances and production of histograms (relative radiance – percent resolution elements). Also, some work was done on image no. 2. As reference it was available the experience of the photointerpreter in the area and the Forestry Map of Spain at scale 1:400.000.

2.6. Agronomic interpretation

It was used mainly false color image no. 2 complemented with other black and white images in bands 5 and 7. The terminal RAMTEK has allowed also some digital processing of image no. 6, although this work was conducted only for checking results. The interpretation was based on the current knowledge of terrain on 12 selected sites. The aerial flight at scale 1:30.000 has also been used.
3. ACCOMPLISHMENTS

3.1. Drainage network of Guadarrama basin

This work was conducted in the following stages:

a) From LANDSAT image no. 2223-10135 (September 1975), a rectangle was selected between lines 540 to 2140 and pixels 1 to 800 of the original digital tape. This subscene was referred to UTM coordinates by means of 8 control points and a second order polynomial algorithm, obtaining an image with pixels of 80x80 m once geometrically corrected. Table 1 shows the geographical coordinates of control points used, their corresponding position in the subscene (line and pixel), and the errors introduced when registering every control point. The errors are given in pixels of displacement along X and Y axis, and in radius vector.

<table>
<thead>
<tr>
<th>Description</th>
<th>Input</th>
<th>Image</th>
<th>Reference</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line</td>
<td>Pixel</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>El Pardo dam</td>
<td>1716</td>
<td>566</td>
<td>N40/32/10.88</td>
<td>W3/47/17.0</td>
</tr>
<tr>
<td>Castrejón dam</td>
<td>653</td>
<td>175</td>
<td>N39/50/10.0</td>
<td>W4/17/49.0</td>
</tr>
<tr>
<td>Navalmedio dam</td>
<td>1954</td>
<td>102</td>
<td>N40/45/4.0</td>
<td>W4/2/7.0</td>
</tr>
<tr>
<td>Tajo-Guadarrama junction</td>
<td>746</td>
<td>815</td>
<td>N39/53/5.0</td>
<td>W4/10/56.0</td>
</tr>
<tr>
<td>City of Toledo (center)</td>
<td>742</td>
<td>558</td>
<td>N39/51/30.0</td>
<td>W4/1/26.0</td>
</tr>
<tr>
<td>Santillana dam</td>
<td>1958</td>
<td>412</td>
<td>N40/43/36.12</td>
<td>W3/48/54.0</td>
</tr>
<tr>
<td>Aulenacia-Guadarrama junction</td>
<td>1547</td>
<td>383</td>
<td>N40/26/10.0</td>
<td>W4/1/46.0</td>
</tr>
<tr>
<td>Guadarrama-Vallehermoso</td>
<td>931</td>
<td>484</td>
<td>N39/59/50.0</td>
<td>W4/1/46.0</td>
</tr>
</tbody>
</table>

Table 1.
The registered image can be seen in figure 1, represented in false color. Such image, and all others appearing in this report, are at scale 1:500,000 with North oriented in their vertical direction.

b) Once registered the subscene a new image was created by the following pixel-values transformation:

\[
I = 16 \frac{B5}{B7+1}
\]

where B5 and B7 represent bands 5 and 7 of the original subscene. The reason why this ratio was selected, instead of the typical B7/B4, is because the closeness of the rivers in the area of study (less than 80 m wide), the existence of vegetation in the margins and the absence of such vegetation in the rest of the image.

c) Image shown in figure 2 represents the ratio above mentioned, once printed through a DICOMED D-47 film recorder. The idea is to discriminate gray levels of more significance in the quotient image by a radiometric adjustment which takes into account the sensitive response of human eye. A histogram was obtained of the ratioed image with the following results:

- mean = 29.27
- RMS = 29.70
- standard deviation = 5.05

being 98% of the pixels with their values comprised between 15 and 38. Then it was done the following transformation:

\[
y = \begin{cases} 
0, & \text{if } gx + b \leq 0 \\
gx + b, & \text{if } gx + b \geq 255
\end{cases}
\]

where \(x\) is the intensity pixel value obtained from (1) and \(y\) is the new value on the transformed image \(I'\). The parameters \(g\) (gain) and \(b\) (bias) were the following:

\[g = 12.67, \quad b = 242.8\]
Figure 4.—False colour composite of the Central Region of Spain, indicating the Guadarrama basin and selected test sites where ground truth was obtained.
with the resulting characteristic values:

mean = 128.52
RMS = 139.96
standard deviation = 55.40

The new image had 22 gray levels distributed from 0 to 255 radiance values.

d) As a last step this image I' was combined to another image L of identical dimensions, which contained information on the frontiers of the hydrographic basin under study and the limits of the maps at scale 1:50.000. Image L had its pixel values equal to zero, except for those corresponding to the frontier lines, whose values were 255. The process for constructing the combined image was the following:

1 - The limits of the hydrographic basin were digitized from the maps 1:50.000, as well as their corners for a later reference. In this way groups Si of points \((x,y)\)_i are obtained in length units (mm) by reference to the South-West corner of the corresponding map at scale 1:50.000.

2 - The points \((x,y)\)_i of each group Si were converted to geographical coordinates (longitude, latitude), which had been extracted from the maps 1:50.000.

3 - With the image I' registered as reference (once geometrically corrected by control points) it was constructed image L by a trasformation which converted geographical coordinates of the points in the groups Si to coordinates line-pixel. This new image L had the same dimensions than the image I', and its pixels had a null value except for those resulting of the transformation of points \((x,y)\)_i which value 255.
Figure 5.—Band 7 of image 2350-10182, obtained in January 1976 with sun angle elevation of 20°
4 - As a last step, and for a better visualization of the frontier line in the hydrographic basin on image L, it was done a process of interpolation between neighbour pixels resulting from the transformation above mentioned. Like this it was obtained a continuous line as representation of the frontier. The algorithm of interpolation constructed was looking for the necessary points of the grid in order to obtain a continuous line between given points \( P_m \) and \( P_n \), with the condition that final points had a minimum distance to the line \( P_mP_n \).

In the resulting image (figure 3) pixels forming continuous line do not have the intensity value of 255, as above mentioned, but their value was chosen for enhancing from the neighbouring pixels. Like this a better visualization of the frontier line is obtained.

Finally, the discontinuities appearing on such continuous lines in figure 3 are due to a last process effected on the image, consisting in a correction by a constant factor \( \cos(\text{latitude}) \) because during the initial registration the image had been considered as located in the equator.

3.2. Hydrographic interpretation

Due to the fact that the currents in Guadarrama river and its tributaries do not attend 80 m in width, the most advantageous combination was a ratio 5/7, which showed riparian vegetation, namely on acid terrains, and dry farming crops in light tone.

A different thing happens with the northern part of the basin, where the presence of prairies and forests in image 5/7 does not show the drainage network. In this area interpretation was completed by means of band 7, selecting the black and white images of higher contrast among those available. Even in such case the absence of contrast and the closeness of the beds
makes difficult the work, doing it impossible very often. However, from image no.7(2350-10182) in band 7, taken in January 1976 with a "sun elevation" of 20 degrees, the shadow effect in the North part of the basin (the most mountainous) allows a correct drawing of it in areas where other LANDSAT images with higher "sun elevation" did not show appropriate. As example, a comparison can be done of figure 3 with figures 4 and 5.

The ensemble of information extracted on the drainage network by means of LANDSAT MSS data shows their goodness for producing synoptic cartography. As comparison are presented here figures 2 and 3 with the hidrographic network superimposed. Figure 2 represents the existing hydrography in Guadarrama basin, as it appears on the old map at scale 1:500,000 published by I.G.C. Figure 3 exposes the same drainage network as it is seen from LANDSAT satellites.

The determination of this network at small scale can be applied to studies of river bed erosion, problems of solid sediments, as well as to the study of surficial runoff, from which it is the major primary exponent. As illustration is presented in figure 2 the existing network of hydrologic rainfall and flow metering stations in Guadarrama basin.

3.3. Geologic interpretation

In the basin Guadarrama river exist only two great geological formations (figure 4). In the upper part of the basin flows a crystalline system mainly formed by granites and, in a minor proportion, by metamorphic rocks. In the mouth of Tajo river and in the opposite margin appear again the granites of Toledo Mountains. Between both outcrops extends the tectonic basin of Tajo, occupied by neogene sediments of gravel, arcose, clay, gypsum and limestone.
The difference between the basement and the deposits of Tajo basin is very clear in LANDSAT images in all four bands MSS. However, the limit between both of them is wordy and not precise, and it can be interpreted only as an extension of the contact located to the SE, in parallel position to the rivers Alberche and Perales.

Fracturation of the complex in this basin is not very intense and the faults, as opposite to the neighbouring basin of Alberche (to the West), have a scarce length. For this reason they cannot be interpreted at the scale of LANDSAT images, with the only exception of one fracture N-S located to the West of Galapagar. The band of metamorphic rocks that, with a general direction N-S passes by El Escorial, cannot be identified; and the same happens with the different sediments that form the deposits of Tajo basin. Geological interpretations of broad areas have allowed Prof. Alía to define the "Extremenian-Castillian vault" (1); a megastructure with more than 350 kms length on its major axis in NE-SW direction. According to such interpretation, the drainage network of Guadarrama river is related to corresponding alignements of such vault. One of them should be used by the Guadarrama itself, experimenting a strong inflexion in the head waters for attending the city of Avila. The Aulencia river should likewise follow another essential alignement of the Extremenian-Castillian vault.

3.4. Forestry interpretation

In a first stage it was intended to evaluate the possibilities of utilization of the information furnished by LANDSAT satellites, in relation with the production of forestry thematic cartography

and its application to the knowledge of several hydrologic variables (runoff, solid contribution, etc).

The Guadarrama basin, from a forestry point of view, has been divided in two areas; one from the river origin (1,800 m) until the spot height of 800 m, the second from 800 m to the mouth of Tajo river. In the first area it can be found the following type of species: Quercus ilex from 800 to 1000 m, Quercus toza from 1200 m to the divisory, Pinus sylvestris and P. pinaster. In the second area the scarce number of trees is represented by Q. ilex.

Initially it was intended the production of cartography of specific masses, and for this purpose it was selected the low area of the basin, South of the axis Brunete-Boadilla del Monte. The reason for this selection was the low influence of relief in the reflectance on that area. Pilot areas have been selected in the holm-oak woods of Batres, Valmojado and Villaviciosa de Odón, and in the reforested pine groves (Pinus pinea) of Navalcarnero and Villaviciosa de Odón. Results, even at level of only one species, do not present any tendency. Histograms, in each MSS band and in their ratios, showed wide intervals of "relative radiance", being superimposed those of different species and without correlation in the case of similar species. As first conclusion it has been established the high influence of the surficial cover of the forest (spread, reforested, etc) in the reflectance. An important factor to consider could be also the small surface of the masses and the rather poor state of them.

Based in such results it was considered a more ample classification which allowed separation of forest masses in conifers and leafy trees. This second possibility was rejected because the low extension of the basin with only a small forest of Q. toza, in the terms of Cercedilla and Navacerrada, which did not
show adequate because its poor vegetative state. In the leafy trees it can be found the gallery vegetation (vegetation installed in the riverbed of annual flood), which normally does not offer a width larger than two pixels and it cannot be used in training fields.

With such premises, it was intended a classification in two classes; the first formed by soils covered with trees and the second formed by soils with farming crops, brushwoods, pastures, fallow lands and lithosols. In the first class three training fields of medium vegetation were selected, while in the second case three others were chosen representing plots of low vegetative cover, as it can be seen in the enclosed table.

<table>
<thead>
<tr>
<th>Class</th>
<th>Descriptor</th>
<th>Location</th>
<th>Dominant species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M1</td>
<td>(40:14:10:45N) 3:50:50:43W</td>
<td>Q. ilex</td>
</tr>
<tr>
<td>1</td>
<td>M2</td>
<td>(40:46:38:07N) 4:03:44:82W</td>
<td>P. pinaster</td>
</tr>
<tr>
<td>1</td>
<td>M3</td>
<td>(40:39:15:19N) 4:08:58:20W</td>
<td>P. pinaster</td>
</tr>
<tr>
<td>2</td>
<td>D1</td>
<td>(40:33:35:91N) 4:00:17:63W</td>
<td>no vegetative cover</td>
</tr>
<tr>
<td>2</td>
<td>D2</td>
<td>(40:09:10:02N) 4:08:29:71W</td>
<td>no vegetative cover</td>
</tr>
<tr>
<td>2</td>
<td>D3</td>
<td>(40:11:50:59N) 3:55:01:66W</td>
<td>no vegetative cover</td>
</tr>
</tbody>
</table>

With the purpose of classifying and producing cartography it was selected an area (Z1) in the lower part of the basin (scarce influence of relief, which is coincident to the area included in sheet no. 581 of the National Topographic Map at scale 1:50,000), and another area (Z2) in the upper part (much more influenced by relief), which is coincident to the area of the basin included in sheet no. 508 of the map.
Results attended with the histograms were positive in all four bands MSS, appearing clearly differentiated the "relative radiances" of soils with and without vegetative cover; namely in band 7, where the reflectance appears comprised between 10% and 20%. Because the training fields could be spectrally separated, through the RAMTEK terminal it was done a classification of areas Z1 and Z2. Classes 1 and 2 were defined by the plots M1, M2, M3, and D1, D2 and D3. Blue color was assigned to class 1, yellow to class 2, and the red was selected for threshold values.

Results in area Z2 were not enough clear, with a 55% of terrain not classified, probably due to the influence of relief (high mountain) and the abundance of pastures (clear mountains).

In the area Z2, results have been satisfactory and in plenty coincidence with the existing thematic cartography, except in the mountain of Valmojado; which can be explained because the poor vegetative state of such area of Quercus ilex. The rest of the area Z1 appears well classified, with the unique error of a part of Guadarrama riverside, included as threshold value. As the trees are holm-oaks an pinus (persistent leaves), this vegetation of gallery along the river can be defined as Populus, Salix, Fraxinus, etc.

3.5. Agronomic interpretation

It was intended on image no:2, dated March 8, 1976. to find out similarities in colors corresponding to identical types of farming crops. The following working schedule was planned:

a) Selection on the image of spots with identical appearance in tonalities.

b) Identification on the ground of the farming crops corresponding to such spots.
c) Possible correlation between tonalities and farming crops.
d) Treatment in computer of the acquired information, with the
   purpose of obtained similar spots of crops existing in the
   basin.
e) Production of a map representing identical crops to those
   studied by photointerpretation techniques.
f) Evaluation of the surface occupied by identical crops.

Only steps a) and b) could be accomplished, being phases c) and d) carried out at the moment of submission of this final report. Points selected on the image for identification in the terrain have been indicated in figure 4. The joined table represents their location and description on the National Topographic Map (N.T.M.) at scale 1:50,000 published by I.G.C.

<table>
<thead>
<tr>
<th>Point</th>
<th>Sheet N.T.M.</th>
<th>Location</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>629</td>
<td>Western margin Tajo river</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>2</td>
<td>629</td>
<td>Western margin Tajo river</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>3</td>
<td>629</td>
<td>Eastern margin Tajo river</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>4</td>
<td>629</td>
<td>Western margin Tajo river</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>5</td>
<td>629</td>
<td>road Toledo-Torrijos intersection to Guadarrama river</td>
<td>irrigation land</td>
</tr>
<tr>
<td>6</td>
<td>629</td>
<td>dry farming crops</td>
<td>olive-groves/vineyards/cereals</td>
</tr>
<tr>
<td>7</td>
<td>629</td>
<td>dry farming crops</td>
<td>olive-groves/cereals</td>
</tr>
<tr>
<td>8</td>
<td>604/581</td>
<td>Eastern margin Guadarrama river</td>
<td>cereals/vineyards</td>
</tr>
<tr>
<td>9</td>
<td>534</td>
<td>around Colmenar Viejo village</td>
<td>pastures</td>
</tr>
<tr>
<td>10</td>
<td>533</td>
<td>El Escorial area</td>
<td>Quercus forests</td>
</tr>
<tr>
<td>11</td>
<td>558</td>
<td>road Villanueva de la Cañada-Brunete</td>
<td>cereals/stubbles</td>
</tr>
<tr>
<td>12</td>
<td>558</td>
<td>mountains</td>
<td>bare soils</td>
</tr>
</tbody>
</table>
The RAMTEK terminal was used with four zones of similar characteristics as training fields in image no.6. Once obtained the histograms of the selected areas, it could not be observed any correlation between them.

4. PROBLEMS

The problems associated to the hydrographic interpretation depend on the resolution of MSS sensor, which is not the adequate to the widths of the rivers to be observed in Central Spain.

Problems in Geological interpretation were related to the small scale of the images worked with, taking into account the small area covered by the basin under study.

The agronomic interpretation posed the following problems:

a) None presence of spots with homogeneous color, of size large enough for a precise identification.

b) Difficult identification on the terrain of isolated spots, unless good points of clear location exist.

c) Difficult location of the corners of training fields when selected via cursor through the RAMTEK terminal.

5. DATA QUALITY

The quality of the images furnished by NASA for this project was, in general, excellent, with good definition and low presence of cloud cover. Reproduction work of the originals conducted by I.G.C. showed adequate quality for the purpose of this work.

The quality of the products obtained through RAMTEK terminal and DICOMED film recorder was also excellent.
6. CONCLUSIONS

6.1. Treatment of the information

The method for enhancing a geographical accident by means of band ratio techniques applied to LANDSAT images is not new. However, a general knowledge of the area under study allows much better results than by the use of conventional quotients. A radiometric correction of the ratioed image even increases the contrast of the desired geographical accident (2).

It has been explained in this report how a new LANDSAT image was created with known data superimposed. Such data could be ground truth, fields or map borders, etc.

6.2. Hydrography

In the aspect of hydrographic interpretation it can be stated the speed accuracy obtained in the delineation of drainage networks at a synoptic scale from LANDSAT images with adequate processing. It is considered of the maximum interest for C.E.H. the knowledge of such networks, their lengths, densities, and all physical patterns detected by the satellite on this subject.

6.3. Geology

Although conclusions obtained by geological interpretation of the basin are really poor and not spectacular from a lithological point of view, it is recognized the great interest that interpretation of other areas could have, even on the same image. In the structural aspect the conclusions of the method are, on the contrary, important from the point of view of the megastructures, although not in the area under study.

6.4. Forestry

Because the characteristics of the mediterranean forest masses of Spain, imposed by the climat and their treatment, it seems that the closeness has a higher influence than the spectral properties of reflectance in each species, being still a long way until the automatic classification of species could be done.

The classification in soils with and without vegetative cover appears clear in flat terrains, although relief, subalpine pastures and atlantic pastures produce a masking of the spectral response of forests. From the point of view of protecting the terrain (fight against erosion), it is convenient to dispose of real cartography updated.

In the future it is intended to accomplish the following working program:

- identification of shrubs
- classification of the different types of forests and thickets
- digitizing of level curves to be introduced through the RAMTEK terminal for evaluating the influence of sun elevation in areas of strong relief
- automatic classification of species, densities and development of them
- evaluation of the flooded surfaces by means of the vegetation of gallery and possible profit of them for cultivating species of fast growing woods (black poplars)

6.5. Agronomy

The agronomic application of LANDSAT images is considered important and useful, whenever exists the possibility of checking the space acquired observations with direct observations on the
ground, namely in real time or as closed as possible to the date of LANDSAT overpass. Concerning the RAMTEK terminal, it is so powerful that even broad areas with the same type of farming crops are displayed in different form, probably due to the following reasons:

a) phenological states of crops  
b) density of sowing  
c) variety  
d) type of soil  

These factors make difficult the current application to agronomy of LANDSAT information at the resolution envisaged today by MSS sensor.

6.6. Epilogue

From the point of view of integrating the types of interpretations here exposed, it is considered that a continuous use of LANDSAT images and the processing techniques here considered, should contribute to obtaining, in a short time and at a reasonable cost, the information required for characterizing hydrographic basins. Thus it is desirable to continue the studies here started for a better application in Spain of the LANDSAT information furnished under this project to the multidisciplinary group involved.