(E76-10493) A METHODOLOGY FOR SMALL SCALE RURAL LAND USE MAPPING IN SEMI-ARID DEVELOPING COUNTRIES USING ORBITAL IMAGERY. PART 5: EXPERIMENTAL AND OPERATIONAL TECHNIQUES (Fairey Surveys Ltd., Maidenhead) N76-31637 HC Unclas G3/43 00493

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Part V. Experimental and Operational Techniques of Mapping Land Use.

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SUMMARY OF SIGNIFICANT RESULTS.

The main problem associated with pre-processing involves the correct selection of the technique and the most convenient scale. The scope of the pre-processing techniques used in this investigation was restricted to the standard material from the EROS Data Center accompanied by some enlarging procedures and the use of the diazo process. After careful examination, the land use classification system outlined in U.S. Geological circular 671 has been accepted as the general framework for land use mapping in this investigation. Investigation has shown that the most appropriate sampling strategy for this study is the stratified random technique. A viable sampling procedure, together with a method for determining minimum number of sample points in order to test the results of any interpretation are presented in the report.

NOTICE

4. TECHNIQUES APPLICABLE TO RURAL LAND USE MAPPING USING LANDSAT MSS IMAGERY

4.1. INTRODUCTION

As mentioned in the previous chapter a detailed appraisal of the main stages of the production of small scale rural land use maps from LANDSAT MSS imagery is required before an adequate methodology can be devised. This is necessary as very few attempts have been made to bring together details of all the relevant stages needed in the overall production using inexpensive and unsophisticated techniques. The general aim of this section is to provide a review of techniques that have been used in relevant studies in order to select a range of appropriate techniques that can be evaluated in the field before formulating an overall methodology. The division into pre-processing, interpretation, classification and ground truth have not been intended to be arbitrary as certain topics are common to several of them, e.g. scale and resolution. But it is thought that the divisions provide the most satisfactory format which permits an adequate consideration of all aspects of this type of mapping. The problem of overlapping topics has been alleviated by cross-referencing.

4.2. PREPROCESSING

4.2.1. General

One of the first problems confronting the investigator involved in small scale land use mapping from orbital imagery is the selection of the most appropriate visual output of the digital data that has been obtained from the LANDSAT multi-spectral scanner. This means that he should be aware of the range of standard pre-processed products which are available to him as well as the pre-processing techniques which he might be able to utilise in order to provide the best materials for the application of visual interpretation techniques.

(all references may be found in bibliography of final contractor's report.)

Pre-processing has been defined by Hempenius (1975) as "the processing or data handling with the purpose of re-arranging compressing, simplifying, enhancing, etc. the data prior to interpretation" and the broad scope of this definition has been accepted for the purpose of this research. But, as one of the main aims of this research is to consider relatively inexpensive and unsophisticated pre-processing and interpretation techniques, computer-based pre-processing techniques utilising LANDSAT MSS digital data will not be assessed. Detailed summaries of these may be found in articles by Simonett (1974) and Steiner and Salerno (1975). Further specific examples of computer based pre-processing techniques may be obtained from Allen (1975); Anuta and McDonald (1971); Hall, Baver and Malila (1974); Haralick and Shanmugan (1974); Langrebe (1972); Leamer, Weber and Wiegand (1975); McDonald, Baver, Allen (1972); Weber et al (1972); Ratti and Capozza (1974); Bressanin et al (1973).

Pre-processed LANDSAT MSS data can be purchased from EROS Data Centre in a-number of different formats (see Table) which may be interpreted in standard form or may be used as the basis for further pre-processing by researchers. The scope of pre-processing techniques that have been employed by investigators is quite wide and ranges from simple photographic enlargements to more sophisticated image enhancement processes. However, the extent to which these techniques can be utilised in operational land use mapping depends upon the objectives of the survey, the finance and time available as well as the resolution and scale limits imposed by the nature of the investigation.

Most of the techniques that have been used in this type of research may be considered under the term image enhancement as most of the other aspects stated in Hempenius' definition, viz re-arranging, compressing

TABLE

LANDSAT MSS PRODUCTS AVAILABLE FROM EROS DATA CENTRE

Aug. 1, 1975

Image Size	Scale	Format
2.2 inch	1:3,369,000	Film Positive for each spectral band
2.2 inch	1:3,369,000	Film Negative for each spectral band
7.3 inch	1:1,000,000	Film Positive for each spectral band*
7.3 inch	1:1,000,000	Film Negative for each spectral band
7.3 inch	1:1,000,000	Paper Print for each spectral band*
14.6 inch	1: 500,000	Paper Print for each spectral band*
29.2 inch	1: 250,000	Paper Print for each spectral band*

* indicates that colour composites may be available in that format

Computer Compatible Tapes (CCTs) are also available for purchase and simplifying are normally carried out by applying computer based techniques to the MSS digital data. Image enhancement has been defined in a variety of ways but for this research it can be considered as "the various processes and techniques designed to render optical densities on the imagery more susceptible to interpretation" (Estes and Senger, 1974). Essentially, the image enhancement techniques that can be used to produce hard copies from LANDSAT MSS imagery may be classified into two broad groups, viz. photographic and electronic. Relevant visual optical enhancement methods (c.f. photographic enhancement techniques) will be discussed in the section dealing with interpretation techniques (see Section 4.3) as they are generally used by researchers to enlarge or combine imagery visually rather than to produce hard copies. Detailed discussions on image enhancement procedures may be found in Simonett (1974), van Genderen (1975) and Steiner and Salerno (1975).

4.2.2. Photographic Enhancement

4.2.2.1. Enlargement

The most commonly used image enhancement technique involves the photographic enlargement of one or more of the four spectral bands of the basic imagery acquired from Eros Data Centre (see Table). These enlargements may be produced in the form of positive or negative black and white or colour film or paper prints at various scales and they have been used in a variety of ways to assist in land use interpretation including mosaics, overlays, etc.. Also there has been an increasing tendency to use transparencies in interpretation due to the level of graininess which permits greater magnification than would be possible with paper prints (Estes and Simonett, 1975; van Genderen, 1975).

The selection of the most appropriate scale that should be used in interpreting LANDSAT MSS imagery has caused a great deal of concern and various viewpoints have been discussed in a separate section (see Section 4.2.4.).

4.2.2.2. Colour

The production of colour composites in hard copy for specific purposes is relatively expensive and investigators have tended to accept the EROS Data Centre false colour composites derived from bands 4, 5 and 7 and presented in film positive or paper print form (Joyce, 1974) (see Chapter 4.3 - Selection of spectral bands - for more details). However, one viable and economic alternative has been the use of the Diazo process which, although not a photographic process in the strict sense, has the capability of producing single colour film transparencies from black and white positive images of selected spectral bands. The base is an optically clear, thin polyester material with high stability which is sensitised with a diazo coating. Development is achieved by passing the film through a dyeline machine. Details of the exposure procedure, etc. are described by Keates (1973). Diazo films are available commercially in a range of colours, eg. red, magenta, yellow, orange, green, violet, blue, cyan, brown. Once the colour transparencies are developed they can then be super-imposed in any desired combinations to form a variety of false colour composites. Various researchers have acclaimed this technique. Hardy, Skaley and Phillips (1974) maintain that they have applied it successfully to produce high false colour images at scales up to 1:150,000 from LANDSAT imagery after balancing the density of the imagery through a step enlargement procedure from the initial 1:3,369,000 chip. Other aspects of their research has been considered in detail in Section 3.2.3.. Little and Scotney (1974) also believe that the Diazo process has great potential but Viljoen and Viljoen (1975) assert that the image definition is poorer than photographic composites (see Section 3.3.3.). After experimenting with the process, the author agrees with the general conclusions of Hardy et al and Little and Scotney. The main attraction of the Diazo process is that it is cheap and that both the materials and the equipment are used in drawing offices throughout the world and, after experimentation researchers may find that it could be used to produce satisfactory imagery that is comparable to the more expensive colour composites available from EROS Data Centre. The use of colour additive viewers has been considered under optical enhancement techniques (see Section 4.3.4.2.).

4.2.2.3. Density slicing

In this process special developing techniques are used to extract and reproduce single grey levels (or slices) which could be used for further investigation of the spectral responses from various types of land use but the procedure is time-consuming and difficult (Simonett, 1974). However, special density slicing film has been made available by several commercial firms and various researchers have investigated their potentialities, e.g. Ranz and Schneider (1971) have considered Agfa-contour film with normal photographs and have experimented with it in association with Diazo film colour composites of the different density slices. Dragg (1974) claims that LANDSAT MSS imagery "because of the uniformity of the data and small look-angle lends itself to this relatively simple technique particularly in level areas" but did not elaborate on its application.

4.2.2.4. Contrast printing

This is a commonly used pre-processing technique that may be used to make slight grey scale differences more detectable in visual interpretation and has been applied to LANDSAT MSS imagery (Simonett, 1974).

Hardy, Skaley and Phillips (1974) have used this technique in their attempts to develop a low cost manual method of enhancing LANDSAT MSS imagery that could be used in land use mapping.

4.2.2.5. Edge enhancement

In this procedure a positive and negative are superimposed, slightly displaced and re-photographed. Edges at right angles to the direction of displacement will appear as white lines on the forward edge and black lines on the trailing edge but other edges will not be enhanced. Simonett (1974) discussed methods of overcoming the problem of directional enhancement by placing the positive and negative on a rotating disc with an exposure light mounted off-axis above the disc. This technique has been used in attempts to detect boundary changes in land use.

4.2.2.6. Image addition

One advantage of this system is its ability to assist interpreters in detecting landscape changes. This can be achieved photographically by combining a positive transparency of a photograph taken at a particular time with a negative of a photograph of the same scene taken at another time and printing a new photograph through both. Areas of change are indicated by light or dark tones whereas areas of no change will be medium grey.

4.2.3. Electronic Image Enhancement Techniques

These techniques which include micro-densitometry, iso-densitometry, electronic dodging and image quantising will not be considered as the cost of equipment prohibits their use in this type of investigation. Detailed discussions of the techniques may be found in articles by Simonett (1974), van Genderen (1973, 1975), Steiner and Salerno (1975).

4.2.4. Image Scale

The problem of selecting the optimum image scale is an important aspect in the overall mapping procedure as it interacts with the resolution of the sensing system and consequently effects the level of interpretation. A compromise must be reached between the image resolution, the operational mapping scale and the objectives of the study. Most investigators using conventional visual techniques have tended to utilize the standard pre-processed LANDSAT MSS imagery which has a maximum scale of 1:250,000 available only as an opaque print but the image resolution is markedly inferior to the prints and transparencies available at 1:1,000,000. Further photographic enlargement leads to poorer image resolution although various researchers have claimed to have successfully used enlargements at much larger scales (Justice et al, 197?; Hardy et al, 197?).

Very little guidance about the most appropriate scales that should be considered with the various types of LANDSAT MSS imagery formats that can be used in land use mapping. Nunnally (1974) commented that "Few studies have been undertaken which have attempted to evaluate the effects of scale and resolution on an interpreter's ability to identify different types of land use". He also claims that the results of those studies that have been attempted have been inconclusive. Joyce (1974) noted that although the scale of enlargement of LANDSAT MSS imagery can usually be determined by the scale of the available maps, it is also dependent upon the quality of the particular imagery that has been selected and the nature of the enhancement equipment available to the investigator. Howard (1974) claimed that there was increasing evidence to show that with adequate ground checking a range of discipline oriented thematic maps could be prepared at 1:250,000. Most subsequent reports have been in the form of general statements rather than critical appraisals and little concrete assistance can be obtained from them. In this investigation the main image scales will be controlled by the available standard formats of the LANDSAT MSS imagery, i.e. 1:3,369,000; 1:1,000,000; 1:500,000 and 1:250,000 although some evaluation at slightly larger scales will be attempted mainly by visual optical enlargement processes (c.f. photographic enlargement).

4.?.5. Resolution

In the interpretation of all remote sensor imagery the resolution of the imaging system puts practical constraints on the accuracy levels that may be obtained. Unfortunately, the term has been given a wide variety of connotations by different researchers in a number of different contexts (see Table). Some writers have clearly defined their use of the term whereas others have either not stated the intended measuring or have adopted a very loose definition which occasionally misleads the reader. Olson (1974 - article written in 1969) has stated that "unfortunately resolution is one of the most misunderstood and misused qualities of the photographic system - at least by photographic interpreters". The situation has become even more uncertain since the advent of other more sophisticated remote sensing systems including multi-spectral scanners, and radar. It has caused Estes and Simonett (1975) to comment that "resolution is a complex subject and the various methods used to measure resolution may not always properly characterise the information content of the image".

It is apparent that there are a number of different types of resolution that should be considered when using and describing the capabilities of orbital MSS imagery. Their relative importance depends on the scale of the imagery and the nature of the survey in which the imagery is employed. The dominent aim of each type of resolution, however, is to maximise the contrast between objects and their background. If

If very little contrast exists then the objects become difficult to identify. The following types of resolution have the most effect on the contrast levels of LANDSAT MSS imagery. Their definitions definitions have been adapted from those provided in Table .

1) Spectral resolution - the number and width of spectral bands within which data is collected. Hence, the spectral resolution of LANDSAT MSS data is four broad bands. These band widths and their relative position along the electromagnetic spectrum are shown in Figure and Table .

2) Spatial resolution (or ground resolution) - the smallest area on the ground, i.e. pixel from which the multispectral scanner can measure radiant energy. The spatial resolution of LANDSAT MSS is 79 m by 79 m.

3) Image resolution - the ability of the entire MSS system to render a sharply defined image. This means the ability to record visually each pixel on the recording base. However, if photographic copying or enlargement occurs, then photographic image resolution should also be considered and this is usually expressed in terms of lines per mm for a given photographic emulsion under given conditions. The combined effect is shown in Table

4) Temporal resolution - the time period (usually expressed in days) between successive orbits over the same area, i.e. the time period between each successive data acquisition of the same area. Temporal resolution is mainly affected by cloud cover and the operating schedule of the recording status.

Other types of resolution, e.g. thermal resolution and intensity resolution, although relevant in other studies have relatively little importance in this type of investigation and, therefore, have not been included in the list of definitions.

The wider range of spectral resolution available with LANDSAT MSS imagery has certain advantages and disadvantages when compared with conventional black and white and colour aerial photographs and these aspects have been discussed in Section 4.2.3.. Besides the problems of image and spatial resolution involved in the visual interpretation of the LANDSAT MSS imagery (see Section 4.3.) they also affect the selection of the most appropriate size of the sampling "point" in field surveys when trying to establish the accuracy level of interpretation. This problem has been considered in Section 4.5.2.4.. The high frequency temporal resolution of the LANDSAT system provides a major advantage in studies involving vegetation cover and further details of its use in this investigation have been provided in Section 4.3.6..

4.2.6. Summary

The main problem associated with pre-processing involves the correct selection of the technique and the most convenient scale and resolution for the interpretation procedure that is considered to be the most appropriate for the task in hand. This is particularly important when using LANDSAT MSS imagery because the spectral responses displayed on the black and white and colour transparencies and opaque prints are relatively unfamiliar to interpreters and a great deal of uncertainty still exists over which combination of scale and spectral bands give optimum visual interpretation conditions. Therefore, until more conclusive evaluations and descriptions of techniques have been published, the use of more refined pre-processing techniques may tend to cause more

TABLE

SOME DEFINITIONS OF TYPES OF RESOLUTION USED IN REMOTE SENSING

Hempenius (1975) p.8 (confining his definitions to multi-spectral remote sensing)	Spectral resolution - the number of bands. In addicion one should know the exact location of the various bands and their width Intensity resolution - the number of levels in which the radiant energy is sampled Spatial resolution - the area on the ground, i.e. pixel, from which the radiant energy is integrally measured during the very short time that the instantaneous field of view is directed to that area Temporal resolution - the number of days between successive flights over the same area, if carried out continuously
Manual of Remote Sensing Glossary (1975) p.2102	The ability of an entire remote sensor system, including lens, antenna, display, exposure, processing and other factors, to render a sharply defined image. It may be expressed as "line pairs per millimetre" or metres, or in many other manners. In radar, resolution usually applies to the effective "beam width" and "range" measurement width, often defined as the half-power points. For infra-red line scanners the resolution may be expressed as the "instantaneous field of view". Resolution also may be expressed in terms of "temperature" or other physical property being measured
Estes and Senger Glossary (1974)	The ability of a remote sensing system to distinguish signals that are close to each other spatially, temporally, or spectrally Ground resolution - the minimum distance between two or more adjacent features or the minimum size of a feature which can be detected; usually measured in conventional distance units, e.g. feet or inches Image resolution - resolution expressed in terms of lines per millimetre for a given photographic emulsion under given situations Thermal resolution - image resolution expressed as a function of the minimum temperature difference between two objects or phenomena
Thaman (1974) p.197	The smallest ground resolvable distance (G.R.D.); that is, the size, length or area of the smallest object discernable on an image, taking into account the difference in contrast ratio across an image
Olson (1974) p.102	The ability of a photographic system (including lens, filter, emulsion, exposure and processing, as well as other factors) to record fine detail in a distinguishable manner
Estes and Simonett (1975) p.977	The ability of a human observer to detect a changing pattern consisting of parallel bars of alternating radiance (see Table)

TABLE

LANDSAT MSS SYSTEM RESOLUTION

(in metres/bar for Band 4)

Based on standard U.S. Air Force tri-bar resolution target

(from Estes and Simonett, 1975)

	High Contrast Scene	Low Contrast Scene
MSS Output	44	97
Input to NASA Data Processing Facility	44	97
Bulk		
70 mm archival film	54	123
70 mm positive (3rd generation)	53	118
9.5 inch positive (3rd generation)	57	136
CCT	44	97
Precision		
9.5 inch positive (5th generation)	79	184
CCT	90	193

problems with interpretation instead of aiding the identification of objects. Arnold (1974) has been particularly critical of the way in which image enhancement procedures have been used and he has stated that "it does appear that these techniques have been employed on occasions in cases where they can offer little advantage and have apparently only been used because they are currently fashionable. This is, of course, a criticism of the experimenters and not the technology. Consequently the scope of the pre-processing techniques used in this investigation will be restricted to standard pre-processed material from EROS Data Centre accompanied by some enlarging procedures as well as some investigatory uses of the diazo process. There is no doubt that more experimental work needs to be carried out to develop a methodology on the role and usefulness of image enhancement techniques in rural land use surveys.

4.3. INTERPRETATION

4.3.1. Introduction

Visual image interpretation has been defined as the act of examining photographs and/or images for the purpose of identifying objects and phenomena and judging their significance (Estes and Simonett, 1975; Am. Soc. of Photogrammetry, 1960). However, the level of interpretation of most remote sensor imagery, including LANDSAT MSS imagery, depends on the quality and nature of the imagery itself, the type of interpretation techniques utilised, the enhancement facilities available, the interpreter's specific and local knowledge and his access to other relevant information, e.g. aerial photographs, publications, statistical data, etc.. In addition, the purpose of the investigation places constraints on the extent and nature of the interpretation procedure.

Conventional photographic interpretation techniques have been used successfully with black and white LANDSAT MSS imagery of individual spectral bands and with colour composites produced from combinations of various spectral bands. Thus, the identification of objects from LANDSAT MSS imagery has involved the use of one or more of the elements of image interpretation, viz. shape, size, tone and colour, texture, pattern, shadow, site, association and resolution. These aspects have been well-documented in articles on the interpretation of black and white and colour aerial photography, e.g. Olson (1973), Avery (1970), Strandberg (1967), Allum (1969), A.S.P. (1960, 1968). Probably the most relevant and recent article dealing with interpretation techniques and their application to a wide range of remote sensor imagery has been presented by Estes and Senger (1975).

In land use studies involving LANDSAT MSS imagery there has been a wide divergence of ideas about which combination of imagery, scale, enhancement techniques and other factors would be best to adopt as the basis for satisfactory visual interpretation. As a wide variety of approaches have been used it is important that many of the ideas and opinions should be brought together in order to establish a satisfactory base from which a framework can be formulated as part of the development of an overall methodology. The aspects will be considered under the following topics; the visual interpretation process, visual interpretation aids, selection of spectral bands, seasonality or the use of multi-date imagery and the interpreter's knowledge of the region being considered as well as his expertise in particular disciplines and his understanding of the relevant remote sensing system. Although they are not necessarily independent, the separation into various topics should permit a wider view of the problems associated with the establishment of a satisfactory interpretation system which could be adopted for use in land use mapping with LANDSAT MSS imagery.

4.3.2. The Visual Interpretation Process

The process of visual image interpretation is a complex multi-stage operation which various researchers have attempted to explain by means of a series of stages or phases. Most of the explanations have originated from the study of the interpretation of black and white aerial photographs but the overall approaches have application in the visual interpretation of other types of remote sensing imagery.

One commonly accepted explanation offers scope for incorporating into the description a methodology for producing small scale land use maps from LANDSAT MSS imagery. The initial stage has been described by various terms including the "observational" stage (Spurr, 1973 - originally written 1957) and the "photo-reading" stage (Vink, 1964; Strandberg, 1967; Benneman and Gelens, 1969). It involves the detection or discovery of an object on the imagery from its background. This is very closely associated with the recognition in which the object's shape, size and other properties permit it to be recognised, "discovered" or "measured" in the physical or psychological sense. As mentioned previously, detailed discussions of these properties (or elements) may be found in most textbooks on photo-interpretation. The most comprehensive, recent statement appears in A.S.P. (1975). Then, its identification by its common name or scientific terminology. But, the level of detection, recognition and identification depends on many factors including the physical characteristics of the object itself, the resolution of the imagery (see Section 4.2.5.), the scale of the imagery (see Section 4.2.4.) and the background knowledge of the interpreter (sometimes called the "reference level"). Various aids, including image interpretation keys have been developed to assist the interpreter during this stage (see Section 4.3.4.3.) but with the interpretation of LANDSAT MSS imagery and the imagery produced by other comparatively recent remote sensing techniques a much more detailed knowledge of the capabilities and limitations of the various environmental and sensor parameters which affect the imagery is required by the interpreter than was required with the conventional aerial photographs. Otherwise, it may lead to the interpretation of certain spectral bands which may produce different results when compared with the interpretation of other bands.

The next stage involves the systematic delineation or division of the identified objects into logical patterns or units on the imagery. The important aspect of this stage is to establish the reliability or accuracy of the boundaries. This may then be followed by a classification stage in which the patterns or units may be described and arranged into various types of classification systems with their individual methods of categorization and codification. The problems associated with the establishment of a satisfactory rural land use classification scheme for use with LANDSAT MSS imagery are discussed in Section [illegible].

The process of visual interpretation is basically a deductive process in which the interpreter progresses through the above stages by consciously or unconsciously using various combinations of the elements of image interpretation. The ability to incorporate these elements depends to a large extent on the specific and regional knowledge of the interpreter (see Section [illegible].3.5.) which may be supplemented by various types of collateral material (see Section [illegible].4.). However, with LANDSAT MSS imagery some of the elements decline in importance due to resolution and scale factors and colour or tone become the most dominant elements (see Section [illegible].5.). Also, the task of integrating the information from the four spectral bands is extremely difficult by visual means (van Genderen, 1975). Colour composites produced from three of the four spectral bands tend to alleviate the problem but further interpretation problems are introduced by the false colour nature of the imagery (see Section 4.?.?.2.).

Although the various stages of conventional photographic interpretation may be followed in the interpretation of LANDSAT MSS imagery, the nature of the physical and psychological processes will differ. Consequently, care should be exercised at each stage in order to determine whether accurate interpretation is, in fact, being carried out.

4.3.3. Selection of Spectral Bands

Unlike conventional black and white aerial photography, the problem of selecting the appropriate data base from a range of spectral bands of pre-processed LANDSAT MSS imagery poses difficulties. The major task is to choose the best spectral band or combination of bands for a particular task as certain bands are more appropriate for interpreting features than others and this has led to a certain amount of disagreement amongst investigators.

The official EROS Data Centre brochure lists some details about the main uses of each spectral band:-

Band 4 The green band 0.5 to 0.6 micrometres, emphasises movement of sediment laden water and delineates areas of shallow water, such as shoals, reefs, etc.

Band 5 The red band 0.6 to 0.7 micrometres, emphasises cultural features. This band gives the best general purpose view of the earth's surface

Band 6 The near infrared band 0.7 to 0.8 micrometres, emphasises vegetation, the boundary between land and water, and land forms

Band 7 The second near infrared band 0.8 to 1.1 micrometres provides the best penetration of atmospheric haze and also emphasises vegetation, the boundary between land and water, and landforms

Howard (1974) had diagrammatically shown how the spectral reflectance curves of several natural surfaces associated with land use studies

(see Fig.). On the black and white imagery the surfaces with high spectral reflectance, e.g. healthy vegetation in band 7 would be nearly white whereas the spectral reflectance from water surfaces in band 7 would be shown as black. The problems associated with interpretation based on tonal responses on the imagery become evident when it is seen that different surfaces give similar spectral reflectances within a band. For example, in band 5 healthy green vegetation and water surfaces give similar reflectance values. This problem is also obvious in band 4 where healthy green vegetation, dry loam and dry grasses have similar reflectances in the shorter wave length region but then diverge in the longer wave length portion of the band. Band 7, on the other hand, shows that the six surfaces indicated in the diagram have wider separation in reflectance and, therefore, should show greater grey-scale variation on the black and white imagery. A recent, detailed discussion of the reflectance characteristics of crops and soils has been presented by Myers et al (1975).

Many investigators associated with land use studies believe that bands 5 and 7 are the most useful bands (de Agredo and Salinas, 1973; Falcone et al, 1974, King and Blair Rains, 1974; la Grange, 1973). Justice et al (1974) consider that the most useful band for erosion and land use studies was band 5 followed by 6, 7 and 4. However, Peterson (1975) states that band 6 was recommended to him by a representative of EROS Data Centre as the best for land use mapping and after investigation he concurs.

An increasing number of investigators maintain that colour composites offer greater scope for interpretation than the black and white imagery. The colour composites are normally produced by exposing three of the four black and white bands (usually 4, 5 and 7) of the same area through different filters onto colour film. However, due to the false colour nature

Fig. Howard (197')

Graph showing spectral characteristics

of the process, colours of objects appear different and this poses specific interpretation problems and investigators are required to adjust to viewing objects in completely new colours than they would encounter in normal colour viewing. For example, healthy green vegetation appears as bright red; clear water appears as black and sediment laden water appears as a light blue colour.

Despite the limitations imposed by the false colour nature of the colour composites, many investigators have found them easier to use than black and white LANDSAT imagery in land use studies. (Rijnberg and van den Broek, 1974; Henry, 1975; [illegible] al., 1974; White, 1974.) Also Joyce (1974) in his summary of interpretation techniques adopted in land use mapping with LANDSAT imagery stated that the most satisfactory results have been obtained by interpreting the colour composites. Howard (1974) asserted that "there was no doubt that the MSS colour imagery at a scale of 1:1,000,000 was quicker and less tedious than black and white imagery at the same scale" and he also believed that more data could be obtained from colour composites. His subjective statement has been partly substantiated by tests carried out on the relative interpretability of SKYLAB Earth Resources Experimental Package photographic imagery and LANDSAT MSS imagery indicate that although S 190-A colour infrared photographic imagery ranked highest in overall interpretability, LANDSAT colour composite imagery ranked second ahead of EREP S 190 B colour, S 190 A black and white infrared and LANDSAT band 7 imagery (Estes and Simonett, 1975).

The projection of three black and white bands through three different filters onto colour film to form a colour composite produces a much broader range of visual stimuli in the form of colour differences. This permits a more detailed analysis than allowed by the 15 steps of the grey scale on each of the standard black and white images of each spectral band. Various researchers have used an intermediate stage between the use of black and white images and colour composites by considering two bands using an additive colour viewer or magnifying stereoscopes with varying results (Carlson, 1974; Bale and Bourden, 1973; van Genderen, 1974). Further combinations have been achieved in additive colour viewers by increasing the number of bands and the colours of the filters (other details of this process are provided in Section 4.3.4.2.). Another type of colour composite has been produced using the Diazo process with black and white MSS imagery. This technique has been in more detail in Section 4.?.2.2. and further enhancement could be achieved by using equi-density film (Nielson, 197?).

Colour is a property of an area and it is this characteristic in association with the areal recording nature of the multi-spectral scanner which gives the LANDSAT MSS colour composites certain advantages in the identification of land use patterns (Hempenius, 1975). As the scale of the imagery decreases, the relative importance of the normal range of interpretation elements changes and colour becomes more important. Tharman (1974) states that "as resolution becomes progressively poorer, the information content of an image decreases. As resolution decreases, size, shape and pattern, shadow and texture decrease in importance as interpretative tools until a point is reached where resolution (spatial) is so poor that only tone and hue can be used as interpretative tools". Therefore, changes in colour between areas due to different levels of spectral reflectance tend to provide the main element for identifying land use types on LANDSAT MSS imagery. But, if the colour difference between two different categories is only slight, then interpretation becomes more difficult. Consequently, the interpreter may seek alternative combinations of enhancements by using a colour additive viewer or other techniques (see Section 4.3.4.2.) but more complexities may be introduced by extending the level of abstraction involved in the interpreting of the false colour process and other enhanced imagery. Very careful interpretation of the unnatural colours created by the enhancement techniques is required and this difficulty can be partly overcome if the interpreter has a high reference level with regard to the vegetation and agricultural practices of the region as well as an understanding of the enhancement techniques (see Section 4.1. .). Finally, if the differences in colour between the land use categories cannot be identified satisfactorily then the classification system must be modified.

4.3.4. Visual Interpretation Aids

4.3.4.1. Introduction

Besides the various photographic and electronic pre-processing techniques that were discussed in Section 4.1. certain other methods can be used to assist in the interpretation of the imagery and these can be considered under the collective term "visual interpretation aids". They include optical enhancement techniques, image interpretation keys and collateral information.

.3.4.2. Visual optical enhancement techniques

These techniques include the use of monocular magnifiers (Galan, 1974; Joyce, 1974; Hilwig et al, 1974), light tables, binocular viewing of image of two spectral bands using a stereoscope to produce an image adding effect (van Genderen, 1974; Hilwig et al, 197') stereoscopy utilising the limited scope for stereoscopy between frames (van Genderen, 1974; Hempenius, 1974). Other investigators have used overhead-projectors, rear-view projectors (Breet et al, 1974), micro-film readers (Galan, 1974), micro-fiche readers (Hardy and Hunt, 1974) 35 mm slide projectors (Howard, 1974) but problems of distortion when projected onto screens has led to limitations in their uses.

A more sophisticated approach involves the use of optical additive colour viewers in which the black and white imagery is used in various combinations with filters to produce false colour images (Howard, 1974; Dale and Borden, 1974; Justice et al, 1974; Carlson et al, 1974; Hilwig et al, 1974). Like the electronic additive colour viewers, this system is more time-consuming and expensive than conventional techniques and according to Joyce (1974) their use has been limited to those investigators with the special skills and equipment needed for the enhancement technique. The main advantages of optical additive colour viewers over electronic viewers are that they have higher resolution capabilities, uniform brightness and easy interpreter interaction but a computer interface is difficult to achieve if further interpretive techniques are required (Estes and Simonett, 1975). As the relatively high cost, special interpretation skills and the time-consuming aspect of optical additive viewers contravene the basic aim of this investigation, i.e. to consider inexpensive and unsophisticated techniques for producing small scale rural land-use maps from LANDSAT MSS imagery, they will not be examined in depth. Further details of both optical and electronic additive colour viewers can be obtained from Estes and Simonett (1975). More details of their use in photographic interpretation can be found in A.S.P., 1960; 1975; Bigelow, 1966; Colwell, 1970.

Nunnally (1974) has been concerned with the problem of training interpreters to use LANDSAT MSS imagery in land use studies and he has suggested that "one way of minimising the effects of experience is to establish interpretation keys". But, as far as can be ascertained no keys have been developed to assist the visual interpretation of LANDSAT imagery. Probably the most common technique that has been adopted has been the process of making the interpreter familiar with the various visual signatures on the imagery by comparing them by means of transparent overlays (Alexander, 1973).

4.3.4. Collateral information

Collateral information is generally accepted as that data or material which provides supplementary details about the region being investigated that can assist in the accurate identification of objects or phenomena on the imagery. It is available in many forms including topographic maps, various types of thematic maps, e.g. soils, vegetation, land use, geology, etc., statistical reports, publications and aerial photographs. Detailed examination of this type of material can provide valuable background knowledge which in turn aids the interpretation and the formulation of a legend or classification system. Some investigators, e.g. [illegible] et al (197[illegible]) prefer to include data collected in the field as collateral but for the purpose of this information it has been considered under the general term of "ground truth" (see section 4.5.).

4.3.5. Interpreters' Reference Level

In many articles dealing with photographic interpretation, the authors have emphasised the importance of the background knowledge or reference level of the interpreter (Wist, 19[illegible]; Nunnall, 1974; Bennema and Gelens, 19[illegible]). They have generally referred to the specific skills and expertise that the interpreter has acquired within specialised disciplines, e.g. soil science, vegetation science, geomorphology and their knowledge of the region being investigated. Without this knowledge, the scope for recognition identification and classification of various objects on the imagery is limited.

The level of interpretation of LANDSAT data also depends on the reference level of the interpreter and various investigators have discussed the relative importance of knowledge in specialised disciplines (van Genderen, 1975; Thaman, 1974) as well as general regional knowledge (Estes et al, 1974; Little and Scotney, 197[illegible]). With the interpretation of land use from small scale LANDSAT MSS imagery, the major concern involves the identification of the spectral and spatial relationships exhibited by the vegetation. Consequently, a broad knowledge of the agricultural practices and the vegetation of the region should be required for optimum data extraction (Bale and Bowden, 1973; Lee et al, 1977). This broad reference level should be supplemented by relevant collateral material (see Section 4.4.4.). However, Nunnally (1974) has expressed concern about the problem encountered by interpreters, having been trained to interpret land use in one region, who are then required to interpret different regions with unfamiliar land uses. He claims that the effects of cultural background or "transition and/or land transfer function" (Scherz et al, 1969) have be a frequently encountered but not adequately assessed.

In addition to the background knowledge mentioned previously, the interpreter should have a detailed knowledge and understanding of the image acquisition facility of the remote sensing. This is particularly important with the interpretation of MSS imagery due to the wide range of combinations of spectral bands that are available to the interpreter (see Section 4.3.3.). His main task is to obtain the best possible imagery at the most appropriate scale so that optimum information extraction is achieved. However, unless he understands the nature of the various spectral responses exhibited by landscape features and their representation at various scales on the imagery, his interpretation skills will be limited even though his specific and regional knowledge may be high. Consequently, an interpreter using LANDSAT MSS imagery to map land use should ideally possess a reference level which emphasises regional vegetation and agricultural practices as well as a detailed knowledge of the various environmental and pre-processing parameters that affect the formation of the imagery.

4.3.6. Multi-date Imagery (or Seasonality Effect)

Another important technique that aids the interpretation of LANDSAT MSS imagery involves the utilisation of the relatively high temporal resolution of the system (see Section 4.?.5.). Theoretically, it is possible with LANDSAT I and II to produce imagery of the same part of the earth's surface every 9 days but, in practice, the weather conditions and operating procedures can extend this quite considerably. However, if imagery can be acquired so that the major seasonal effects of the vegetation are recorded, the task of interpreting rural land use can be simplified. Ideally, the imagery acquisition should be "coupled" with the vegetation cycles of the vegetation of the area being studied (Estes and Simonett, 1975) but this is very difficult to achieve. Most researchers claim that colour MSS imagery from at least two permit maximum potential for identification (Estes et al, 1974; Place, 197?; Peterson, 1975; Justice et al, 197?). Also the dynamic nature of the vegetation permits scope for other types of photographic enhancement techniques, e.g. edge enhancement to detect boundary changes and density analyses to detect changes in crop patterns (see Section ?.?.?.).

4.4. LAND USE CLASSIFICATION SYSTEMS

As discussed previously (see Section), the problem of developing a satisfactory land use classification scheme has caused considerable concern to some investigators using imagery obtained from orbital sensors (Anderson, 1971; Nunnally, 197?; NASA, 1974) whereas others have been content to develop ad hoc systems for particular areas being investigated (Rudd, 1971; Parry, 197?). Most researchers agree that no single classification system can be devised that would be suitable as a basis for all types of land use mapping. This is mainly due to a combination of factors including the purpose of the map, the final mapping scale, the resolution and quality of the imagery, regional characteristics, adequate descriptions of categories and the major land use factors that should be included.

The need for a broad framework in order to bring some form of standardisation between the mapping programmes by different organisations has been recognised in the United States and various attempts have been made to produce systems suitable for use with orbital imagery. Anderson (1971) outlined his ideas by proposing two systems for consideration by interested organisations. However, his approach, based on fixed a priori classifications has not been accepted by all researchers as a satisfactory solution. For example, Nunnally (1974) and Mower (197?) prefer the inductive approach to land use classification recommended by Clawson and Stewart (1965) and Nunnally and Witmer (1970) in which the interpreter should interpret land use in as much detail as possible within the limitations imposed by the scale and resolution of the imagery and then group the used into categories most appropriate to his own investigation. Nunnally believes that "if basic classes were properly defined and adequately described, the original data could then be used effectively by others since all detail would have been preserved". Anderson (1971) agreed with the criticism which was also presented by Nunnally and Witmer (1970) that was quite probable that gaps would not be properly filled by using a pre-conceived classification. But, he asserted that an hierarchical arrangement appropriate to a particular need for a land classification system seemed to be necessary in order to guide the interpretation of remote sensor imagery. He used the argument that the inductive approach could lead to a misdirected and possibly expensive effort which may not be needed for a particular purpose. Consequently, in his initial attempts to produce satisfactory guidelines for the preparation of land use maps from orbital imagery at scales ranging from 1:250,000 to 1:2,500,000, he outlined two schemes for consideration (see Tables and). The first scheme was an attempt to devise a more activity oriented or functional categorization which would be compatible with some of the classification systems that were in widespread use. This scheme was intended for use with orbital imagery in conjunction with information obtained from other sources. The other scheme was Anderson's idea for a classification system that could be used over the whole of the United States. It was designed so that little or no supplementary information from other sources was necessary but it assumed that vegetal cover surrogates could be effectively used to identify activity-oriented uses. Both schemes were designed to meet the requirements of a set of criteria which Anderson developed in order to gain a better understanding of current problems related to producing effective classification schemes for use with remote sensor imagery at scales ranging from 1:250,000 to 1:1,000,000.

The background research by Anderson provided part of the framework from which the Inter-Agency Steering Committee on Land Use Information and Classification attempted to develop "a natural classification system that would be receptive to inputs of data from both conventional sources and remote sensors on high-altitude aircraft and satellite platforms, and that would at the same time form the framework into which the categories of more detailed land-use studies by regional, state, and local agencies could be fitted and aggregated upward for more generalized smaller-scale use at the national level". The committee was composed of representatives from the Geological Survey of the United States Department of Interior, the National Aeronautics and Space Administration, the Soil Conservation Service of the United States Department of Agriculture, the Association of American Geographers, and the International Geographical Union. Its work was supported by N.A.S.A. and the Department of Interior and was co-ordinated by the U.S. Geological Survey. The Steering Committee accepted the basic premise that a flexible land use classification scheme was highly desirable in the United States where for many years data had been collected independently and with little

TABLE

SCHEME I of Land Use Classification System Proposed by
J.R. Anderson, Photogrammetric Engineering, 37,
4, 379-387, (1971)

A Tentative Classification Scheme for Use with Orbital Imagery and with Some Supplementary Information for Making Land Use Maps for the United States Ranging in Scale from 1:250,000 to 1:2,500,000

(This scheme assumes availability of some supplementary information from other sources. Vegetal cover terminology in parenthesis where applicable.)

I Resource Production and Extraction
- A. Agricultural
  - (1) Crop Production (Cropland)
    (Cropland-harvested except for orchards, groves, and vineyards; cropland used only for pasture; and cropland not harvested and not pastured)
    - (a) Irrigated Crop Production
    - (b) Non-Irrigated Crop Production
  - (2) Fruit and Nut Culture (orchards, groves, vineyards)
    - (a) Irrigated Fruit and Nut Culture
    - (b) Non-Irrigated Fruit and Nut Culture
- B. Grazing (Grassland and Shrubland)
  - (1) Rangeland Grazing (Rangeland)
    (Native grasses, shrubs and brushland including sage brush, scattered mesquite and some other shrub types in the West)
  - (2) Livestock Pasturing (Pastures)
    (Tame grasses and legumes and scattered brushland in the East)
- C. Forestry
  - (1) Non-Commercial Tree Raising (Arid Woodland)
    (Generally of little commercial value for timber or wood products but may be of value for watershed protection, grazing, wildlife habitat and recreation)
  - (2) Lumbering and Pulping (Forest Land)
- D. Mining and Quarrying

II Transportation, Communication and Utilities
- A. Motoring (Highways)
- B. Railroading (Railroads)
- C. Flying (Airports)
- D. Communication and Utility Activity (Communication and Utilities)

III Urban Activities
- A. Urbanized Livelihood Areas (Urbanized Land) (1970 definition used determined by the Bureau of the Census)
  - (1) Industrial (Industrial Land)
  - (2) Commercial (Commercial Land)
  - (3) Residential (Residential Land)
  - (4) Other Livelihood (Other Land)
- B. Other Urban Livelihood (Other Urban Land). (Populated places of more than 2,500 but not including urbanized areas)

Table (conc.)

IV Towns and Other Built-Up Livelihood Areas (Town and Built-Up Land). (With a lower areal limit which is identifiable through interpretation.)

V Recreational Activities
   A. Mountain Oriented (Mountains)
   B. Water Oriented (Water Bodies)
   C. Desert Oriented (Desert)

VI Low-Activity Areas (Other Land). (Excluding land of these types on which land using activities are found.)
   A. Low-Activity Marshland Oriented (Marshland)
   B. Low-Activity Tundra Oriented (Tundra)
   C. Low-Activity Barren Land Oriented (Barren Land) including lava flows and mountain peaks above timber line

VII Water Using Activities (Water Bodies)

Scheme II of Land Use Classification System proposed by
J.R. Anderson, *Photogrammetric Engineering*, 37,
4, 3[illegible]-337, (1971)

A Tentative Classification of Land Use with Orbital Imagery but with Little or No Supplementary Information for Making Land Use Maps Ranging in Scale from 1:250,000 to 1:2,500,000

(This scheme [illegible] little or no supplementary information from other sources but the assumption is made that vegetal cover [illegible] can be effectively used to identify some activity-oriented uses)

I Agricultural (with no distinction attempted between cropland and orchards, groves, and vineyards [illegible] non-irrigated)

II Grazing

III Forestry

IV Mining and Quarrying

V Transportation, Communications, and Utilities ([illegible] order only)

VI Urban Residential

VII Recreational (only [illegible], water bodies, desert, etc., [illegible] surrogate [illegible] and only [illegible] purpose [illegible])

VIII Low Activity [illegible] ([illegible]) ([illegible], tundra and barren land [illegible] including those classified by use of surrogates and inference as recreational)

IX [illegible] Using [illegible] ([illegible])

[illegible] features [illegible] at the national level. This [illegible], [illegible] uses [illegible] specific purposes [illegible] for [illegible] purposes only [illegible]". Hence, [illegible] compatible with [illegible].

[illegible] policy [illegible] Land Use Information and Classification [illegible] held in [illegible] 1971 and [illegible] local [illegible] and [illegible] ensuing discussion [illegible] should [illegible] classification [illegible] should [illegible] information [illegible] categorization" and [illegible] would recognize the [illegible] compatibility with other more [illegible] levels of land use classification in the [illegible] system [illegible] currently in use in the United States.

As well as utilizing the previous [illegible] contributions by Anderson, the steering committee considered other relevant [illegible], including research carried out by Hardy et al (1971) and Rehringer (1971). Finally, the recommended system was submitted for review and comments by interested organizations and individuals [illegible]. Geological Survey Circular 671 entitled "A Land Use Classification System for Use with Remote Sensor Data". Several interesting [illegible] have been adopted in this system. Firstly, the land cover orientation [illegible] the two most generalised levels, i.e. the levels [illegible] concerned with [illegible] inventory and detailed descriptions of each category have been provided in the circular. The activity aspect of land use is utilised in the third and fourth levels of categorization but have not been described in detail because they were beyond the scope of the investigation. Secondly, four classification levels were developed on the assumption that different sensors could provide information for different levels of classification (see Table). The committee proposed that, due to the relatively small scale of the imagery, Level I could only provide a general classification based major differences in land cover, whereas Level II, based on larger scale imagery and supplementary information permitted the complexity of the system to be increased (see Table). In addition, the committee accepted the criteria suggested by Anderson (1971) (see Table) and the system was designed to meet these requirements.

The definitions for each of the categories in Level I and II were sub·ected to testing and evaluation by the U.S. Geological Survey in three regional projects, viz, the Central Atlantic Regional Ecological Site (CARETS), the Phoenix Pilot Project, and Land Use Mapping for the Ozarks Regional Commission. Initial tested mainly involved imagery obtained from high altitude flights but the system was later found to work satisfactorily when used with satellite imagery. Other organisations have used the system (Carlson et al, 1974; Dornback and McKain, 1974; Hardy et al, 1975) and according to Lietzke and Stevenson (1974) investigators have found that all Level I and II categories with the exception of Level II. Institutional could be delineated. They also stated that investigators have differed in the number of categories that they have been able to detect ranging from 6 Level I categories to 34 categories including 7 Level I, 16 Level II and 11 Level III. They also listed a number of land use categories which have been detected on LANDSAT imagery which were not included in U.S. Geological Survey Circular 671 (see Table). Some of these categories have been included in the amended version of the classification (Anderson, 1974)

TABLE

LAND USE CLASSIFICATION LEVELS

(from Anderson et al, (1971), U.S. Geological Survey Circular 671)

Classification Level	Source of Information
I	Satellite imagery, with very little supplemental information. Concerned with imagery obtained at scales of 1:250,000 or smaller
II	High altitude and satellite imagery combined with topographic maps. Concerned with imagery obtained at scales of 1:100,000 or smaller
III	Medium altitude remote sensing combined with detailed topographic maps and substantial amounts of supplemental information. Concerned with imagery obtained at scales at 1:40,000 to 1:15,000
IV	Low altitude imagery with most of the information derived from supplemental sources. Concerned with large scale imagery

TABLE

LAND USE CATEGORIES DETECTED ON LANDSAT-1 IMAGERY WHICH ARE NOT IN LEVELS I AND II OF CLASSIFICATIONS IN THE U.S. GEOLOGICAL SURVEY CIRCULAR 671

(from Lietzke, K.R. and Stevenson, P.A. (1974))

Mobile Homes
Parking Lots
Unimproved Open Space (bare)
Improved Open Space (irrigated)
Unimproved Open Space (with trees)
Low Density Residential
High Density Residential
Developer Open Space (urban)
Rural Open Land
Right-of-Ways in Forest
Rural Settlements
Wooded Rangeland
Soy beans
Corn
Exposed soil
Winter Ryegrass
Stubble
High Density Single Family
Low Density Single Family
Mixed Multiple and Single Family

Agricultural (plowed)
Agricultural (non-plowed)
Extractive (mines)
Extractive (tailing pipes)
Extractive (basins)
Extractive (gravel pits)
Sanitary Land Fill
Water (natural basin)
Water (excavated basin)
Wetlands (Northern Bogs)
Wetlands (Southern Perennial)
Wetlands (Southern Seasonal)
Low Income Residential
Coastal Strand
Coastal Salt Marsh
Coastal Sage
Woodland Savannah
Riparian Vegetation

(see Table) but, as stated in the circular, the system was designed to be flexible within certain limits and, therefore, a particular organisation could modify it providing the recommended criteria were met.

After careful examination of its development and structure and on the basis that it is the only nationally accepted land use classification system for use with remote sensor imagery as well as the fact that it has been successfully tested, evaluated and implemented by many U.S. organisations, the system has been accepted as the general framework for land use classification in this investigation. Additionally, the system outlined in the U.S. Geological Circular 671 would probably be more acceptable to overseas organisations in an overall methodology for the production of land use maps rather than the inclusion of a completely new and virtually untried system. The U.S. system is quite flexible and should meet the needs of most countries in providing a general working framework from which a standardised land use classification system could be developed for the particular situation.

4.5. GROUND TRUTH PROCEDURES

4.5.1. Introduction

The use of the term "ground truth" in remote sensing has caused a certain amount of controversy. Some investigators including Estes (1974), Savigear et al (1975) have stated or inferred that it is quite adequate and they have not been concerned with interpretations of its literal meaning. On the other hand, other investigators, e.g. Lee et al (1975) have emphatically rejected the term in favour of "ground investigation" or "ground data". They believe that "ground truth" is jargonistic and that it is a vague and misleading term which suggests that "the truth may be found on the ground". For the purpose of this investigation ground truth has been accepted as a commonly adopted and generally understood term which has been used to describe the fieldwork associated with the establishment of a detailed record of the "on-the-ground" situation in order to validate the interpretation of remote sensor imagery. This aspect has often been criticised by researchers as the most neglected aspect of remote sensing investigations (Benson et al, 1971;).

The amount and type of ground truth data acquired usually depend upon the nature of the project being undertaken, the quality scale and resolution of the imagery, the range of interpretation techniques, the availability of supplementary information including topographic maps, reports and statistical data. Therefore, careful selection of the variables that should be investigated and the extent of their measurement and/or description should be a major consideration in any mapping programme based on remote sensor imagery. In this investigation the emphasis is placed on the collection of data in the operational sense rather than the more strictly controlled basic research approach in which very detailed measurements of surface and sub/surface variables may be taken at various stages before, during and after the acquisition of the imagery in order to establish environmental parameters which significantly affect the image characteristics, e.g. Curtis et al, 1974; McDonald et al, 1973.

The data will be used initially to ascertain whether the preliminary interpretation was correct (i.e. whether the required accuracy levels are attained) and additional information collected at the sample sites will be used to determine reasons for possible mis-interpretations and whether the classification system is satisfactory. Accordingly, the interpretation of image patterns covering comparatively large land surface areas on small scale imagery is the dominant problem instead of trying to establish the possible causal relationships between the various image responses and environmental factors as attempted in the more intensive ground truth studies.

As the major aim of this research is to present a methodology for the rapid production of small scale land use maps using unsophisticated techniques, the nature of the variables to be observed and the development of an overall sampling procedure that would permit quick collection and evaluation of data therefore forms an important stage in the investigation. But, in addition, the extent of the ground truth data collection is closely tied to the structure of the classification system which, if correctly established, has certain controlling requirements or criteria that tend to regulate the scope of the inquiry (see Table). These criteria usually determine the accuracy levels to which imagery should be interpreted, the minimum size of areal units and other aspects which can affect the nature of the overall ground truth procedure. Also, the majority of ground truth information in this type of investigation will normally be collected after the LANDSAT MSS data has been recorded at the ground receiving station. This situation arises due to a combination of factors including the operating schedule of the receiving station, the data processing time, evaluation of the imagery for cloud cover and spectral qualities, and delivery time. Consequently, the dynamic nature of the landscape, especially vegetation patterns must be taken into consideration when collecting ground truth data in this kind of study. Most investigators recommend that imagery from different seasons should be used if possible so that a reasonable representation of the spectral responses can be observed (see Section 4.3.6.). This means that, as well as the careful selection of variables and the most appropriate sampling procedure, the most suitable time or times for field checking should be selected in order to avoid expensive and time-consuming field surveys. A more detailed discussion of seasonality and its effects on interpretation is presented in the section on Interpretation Techniques (see Section 4.3.).

4.5.2. Sampling Procedures

4.5.2.1. General

Due to time and cost factors it would be virtually impossible, in the practical sense, to check completely each land use parcel throughout any region, therefore, a valid sampling procedure is required. Unfortunately, different viewpoints and a certain amount of uncertainty exists about which approach is most appropriate and various researchers have attempted to provide satisfactory compromises between theoretical and practical demands. Sampling techniques in land use surveys have ranged from simple North-South and East-West traverses and the identification of doubtful points (Kriesman, 1969) to multi-stage strategies (Aldrick, 1971; Rehder, 1973).

During recent years financial and temporal limitations combined with the problem of adequately representin important minor classifications in the areal sample have tended to focus the attention of researchers involved in land use surveys towards some form of stratified sampling technique rather than a strictly random sample. The major difference between the two is that the areal sample space is divided into strata and each strata is treated as a separate sub-universe in which simple random sampling is employed. (Kelly, 1970). However, no complete description of appropriate stratified random sampling procedures applicable to this investigation can be located. Most researchers have stated that they have adopted a particular strategy without fully describing the techniques adopted for selecting sample sizes, random sites, size of sample sites and the criteria adopted for accepting or rejecting the sites.

Zonneveld (1972) has strongly emphasised that random sampling in land evaluation surveys tends to give too much prominence to the larger areas to the detriment of smaller areas which may be equally as important as the larger areas. He believes that the selection of points within a fully homogeneous area as indicated by interpreted patterns on the imagery should be random rather than using an overall random sample. In a later article he states that "pure random sampling is only appropriate in pure scientific surveys of small areas, where nobody is waiting for the results, except the scientist, who is amusing himself and can afford to spend much time". (Zonneveld, 1974). However, he does not present an in-depth account of his technique and he does not give any indication of the number of sample points required with each category other than "the total number of samples to be taken is then divided between these preliminary communities".

In an attempt to evaluate land classification procedures using simulated space photographs, Rudd (1971) considered that stratified random sampling was the most appropriate. After interpretation, the area of each category was measured and the smallest category (in area) was allocated five sample points and the other categories were allotted sample points in proportion to their respective areas. No reason was given for adopting five sample points for the smallest area.

Dudt and van der Zee (1974) have discussed the importance of ground checks in the identification of rural land use by photo-interpretation in order to verify all non-identifiable and ambiguous objects as well as sampling each category to check to accuracy of interpretation. No indication of sampling method or suggestions about the appropriate number of sampling sites was given but they did include some criteria for establishing interpretation accuracy including the 85-95% limits suggested by Anderson (1971).

Stobbs (1968) has described how he used a random sampling technique to measure land use in Malawi. In effect, it is a stratified random sampling method because he actually stratified his region by using prescribed areas on individual aerial photographs and calculated the number of points to be sampled on each photograph by using a predetermined formula (see Table). Although it is one of the few published reports where the mathematical basis for determining the number of sampling points is adequately detailed, the design parameters do not permit it to be used in this investigation. A similar sampling approach utilising the same formula has been carried out in Nigeria by Alford et al (1974).

Multi-stage sampling procedures have been used in studies associated with the production of land use maps from LANDSAT imagery. Usually, the interpretation of the land use patterns on the orbital imagery becomes the first stratification in a multi-stage design. This is then accompanied by several stages of sub-sampling using low and/or high altitude photography and/or ground data acquisition to quickly and efficiently check land use interpretations. Unfortunately, the problem of insufficient published details about this type of sampling design applied to visual techniques still exists. Poulton et al (1975) in a review of synoptic resource inventories claimed that "methods and sampling theories developed primarily in forestry (Langley, 1969) are beginning to be applied successfully to various rangeland problems (Driscoll and Francis, 1970; Johnson, 1973; Langley, 1974)". No further details were provided and, unfortunately two of the last three references quoted by Poulton were personal communications and the other could not be located. Therefore, specific details of their approaches would not be investigated. However, Aldrick (1971) has utilised Langley's extension of the theory of probability sampling to develop multi-stage sampling designs for timber mortality surveys and Natural Forest management plan inventories in attempts to determine gross volumes of timber from small scale imagery. But, the procedure is not directly applicable in this investigation as it involved larger scale imagery and was primarily designed to estimate timber volumes.

TABLE

DETERMINATION OF THE TOTAL NUMBER OF POINTS REQUIRED TO SAMPLE THE COMPLETE PHOTO COVER OF AN ECOLOGICAL, OR ADMINISTRATIVE, UNIT IN ORDER TO PROVIDE AREA ESTIMATES OF VARIOUS LAND USE CATEGORIES, WITHIN SELECTED ERROR LIMITS

From Stobbs, A.R., 1968
The Cartographic Journal, 5, 2, 107-110

$$N = (100-P) \cdot \frac{38,400}{P \times E^2}$$

N = the total number of sampling points

P = the percentage of the total area of the ecological or administrative unit occupied by the most critical land use category (in the first instance, P is usually an estimate) made on the safe side

38,400 = a constant based on Student's "t", taken at the 95 per cent level of probability

E = the percentage error within which results can be expected to fall in 95 per cent cases

Thus, if the most critical land use category covers some 5 per cent of the total area of the unit, and the sampling error is to be no greater than 5 per cent then substituting in the above formula, we get

$$N = (100-5) \times \frac{38,400}{5 \times (5)^2}$$

$$= 29,184$$

Thus, in this example, if 1000 photos are involved the central portion of each photograph should be sampled by a templace having 29 randomly distributed points

In summary, stratified random techniques have been greatly accepted as the most appropriate method of sampling in land use studies using remote sensor imagery so that smaller areas can be satisfactorily represented. But the problem remains about how to select the best sample for each category. Several alternative methods have been used, e.g.

(1) stratify the region geometrically and then randomly select points within each or rectangle (Berry and Baker, 1968). The number of points may be determined by utilising formulae (e.g. Stobbs, 19.3, Alford et al, 1974),

(2) stratify the region by interpreted land use categories and then estimate the total number of sample points that could be visited due to the constraints imposed by time and money and then distribute them proportionally by area (e.g. Zonneveld, 1974),

(3) stratify the region by interpreted land use and then allocate a certain number of sample points to the category with the smallest area and then distribute sample points to the other categories in proportion to their areas (e.g. Rudd, 1971).

It is considered that the above methods do not provide sufficient statistical justification for the allocation of sample points in each category of rural land use utilizing LANDSAT MSS imagery. Consequently, a more detailed and more reliable method for determining the most appropriate (i.e. minimum) sample size should be ascertained.

The method proposed by the author is explained and justified in the next session on Sample Size. It is this method which was adopted for use in the ground truth phase of the project as descrived in chapters and . The writer gratefully acknowledges the assistance and guidance of Dr. A. Hay, Senior Lecturer in the Department of Geography, University of Sheffield, in the formulation of the statistical sampling methodology which the author has adapted for use in remote sensing studies.

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4.5.?.?. Sample si e

As one of the basic objectives of the present study is to make a classification of rural land use on the basis of LANDSAT MSS imagery, the function of the ground truth survey in such an operational system is to utilize a sound statistical sampling design which will test the correctness of the attribution by interpretation of specific sites to classes in the classification. That is, for any sample point, it should be shown whether the remote sensing attribution to a class within the classification is correct or in error.

Some of the main aspects that need to be considered in such a remote sensing sampling design are:-

(i) the frequency that any one land use type (on the ground) is erroneously attributed to another class by the interpreter. For example in Table $^{3}/15$ of A is erroneously attributed to the other classes;

(ii) the frequency that the wrong land use (as observed on the ground) is erroneously included in any one class by the remote sensing interpreter. For example in Table $^{5}/17$ of A attributions are erroneously interpreted;

(iii) the proportion of all land (as determined in the field) that is mistakenly attributed by the interpret r. For example, in Table $^{3?}/51$ of all attributions are incorrect; and

(iv) the determination of whether the mistakes are random (so that overall proportions on approximately correct), or subject to a persistent bias. For example, in Table is there a significant tendency to mis-attribute land use C (on the ground) to category A, i.e. $^{4}/1.?$

Thus the objective is to design a sampling and statistical testing procedure which will allow an approximate answer to each of these aspects.

TABLE

MATRIX SHOWING HYPOTHETICAL NUMBERS OF SITES IN ACTUAL AND INTERPRETED LAND USE CATEGORIES

LAND USE (on the ground)

LAND USE (interpreted from imagery)

	A	B	C	Sum
A	12	1	4	17
B	2	19	0	21
C	1	0	12	13
Sum	15	20	15	51

In order to determine the optimum sample size* for a stratified random sample of a region which has been mapped by remote sensing techniques, it is necessary to consider, first of all, one land use type or category (stratum) which has been identified from the LANDSAT imagery. A sample of x points in that land use type can then be selected, and the number of errors (f) checked in the field.

If such a procedure adopts a very small sample (e.g. $x = 10$), the number of errors would normally also be small (e.g. $f = 0, 1, 2, 3, \ldots$). However, the achievement of perfect results (i.e. $f = 0$) in such a small sample does not imply that the method is error free, as such a result may occur by chance in a situation where a substantial proportion of the land use classification was in fact, erroneous. This point has seldom been appreciated by many image interpreters when checking the accuracy of their remote sensing land use survey. This proportion of the interpretation which is in error, would, however, be identified in a very long run study, and is normally called P% (or p as a decimal fraction). The probability of making no interpretation errors when taking a sample of x from a remote sensing based classification with real errors having a probability - p is given by the binomial expansion $(p + q)^x$ in which $q = 1 - p$. In the case of no errors in the interpretation, the last term of the expansion is the only one of interest (i.e. q^x).

Table   shows the probability of scoring no interpretation errors in samples of varying sizes taken from a population with a range of real error proportions q. Examination of this table shows that no error sample results can quite easily arise in small samples even when the true

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* by "optimum" sample size is meant the minimum number of points that need to be checked in the field in order to meet a specification requirement of 9% accuracy. Especially for low cost, operational surveys, it is critical that a method of sampling is used which is both reliable and fast (i.e. the method should enable the executing body to meet the accuracy levels required in the shortest possible time).

error rate is high. Taking the conventional probability level of 95%/5%, it is clear that the table can be divided into two parts by a 'stepped' line. Above and to the left of the line, the probabilities of obtaining error free sample results are low, even when true errors may be present in appreciable numbers. On the other hand, below and to the right of the line, it is possible to identify the high probability that these error free results could have been obtained except from a method which was not truly error free. This shows that, if the permissible error rate in image interpretation is predetermined, for example, 85-90% as suggested by the U.S. Geological Survey Circular 671 (Anderson et al, 1972) or as required in an operational job specification, the sample size for each land use stratum necessary for 85% interpretation accuracy should be at least 20, and for a 90% accuracy, it should be at least 30. Thus, by using this table, the <u>minimum</u> sample size required for checking any interpretation accuracy level can be determined. It is a minimum because for any smaller sample size even a "perfect" (i.e. error free ground check) result signifies very little. Tables and provide more detailed calculations of the probabilities of scoring errors in samples of varying sizes with specified interpretation levels of 85% and 90% respectively.

Although strictly speaking a sample of the calculated size should be selected for each land use classification type (or stratum), it is recognized that some land use categories will occupy such a small proportion of the total area (e.g. reservoirs, salt lakes, small forests), that such a sample size would be difficult to obtain. In such cases it is normally feasible to visit each of these sites during the field check in order to verify the accuracy of interpretation.

4.5.2.3. <u>Sampling strategy</u>

It has been demonstrated above that a minimum sample size of 30 is necessary for each land use type in order to meet the U.S. Geological

TABLE

PROBABILITY OF SCORING NO ERRORS IN SAMPLES OF VARYING SIZES FROM A POPULATION WITH A RANGE OF REAL ERROR PROPORTIONS OF

SAMPLE SIZE

	q \ x	5	10	15	20	25	30	35	40	45	50	60
specified interpretation accuracy	.99											0.5472
	.95						0.[illegible]14[illegible]	0.1[illegible]61	0.1225	0.0994	0.07[illegible]9	0.0[illegible]1
	.90			0.2059	0.121[illegible]	0.0713	0.0[illegible]24	0.0[illegible]50	0.0148	0.0087	0.0052	
	.85			0.0374	0.0333	0.0172						
	.80		0.1074	0.0352								
	.70	0.1681	0.0282									
	.60	0.0778										
	.50	0.0313										

——— stepped line indicates approximate .05 level of probability

TABLE

PROBABILITY OF SCORING ERRORS IN SAMPLES OF VARYING SIZES FROM A POPULATION WITH REAL ERROR PROPORTION OF 85%

i.e. THE SPECIFIED INTERPRETATION ACCURACY LEVEL IS 85%

number of errors / sample size	0	1	2	3	4	5
15	.0374					
20	.0333	.1358				
25	.0172	.0759	.1607			
30	.0076	.0404	.1034			
35	.0034	.0209	.0577	.1218		
40			.0365	.0315		
45			.0206	.0590	.0963	
50				.0319	.0561	.1072
55				.0139	.0434	.0781
60					.0275	.0544
65						.0365

——— stepped line indicates approximate .05 level of probability

TABLE

PROBABILITY OF SCORING ERRORS IN SAMPLES OF VARYING SIZES FROM A POPULATION WITH REAL ERROR PROPORTION OF 90%, i.e. THE SPECIFIED INTERPRETATION ACCURACY LEVEL IS 90%

sample size \ number of errors	0	1	2	3
15	.2059			
20	.1216			
25	.0718	.19[illegible]4		
30	.0424	.1[illegible]13		
35	.0250	.0973		
40		.0[illegible]57		
45		.043[illegible]	.1067	
50		.02[illegible]	.0779	
55			.0553	.1005
60			.0393	.0344
65				.0636
70				.0470

——— stepped line indicates approximate .05 level of probability

Survey Circular 671 criterion of 90% interpretation accuracy in land use surveys using remote sensor imagery. To locate these 30 points, random point sampling within land use type (or strata) can then be performed by sampling using random spatial coordinates. By this method, each random point is attributed to the interpreted land use type in which it falls until a sufficient number of points (30) has been achieved in all categories. Once one land use type has been sufficiently sampled, further points that fall in that type may be ignored, whilst the random sampling continues until all types have 30 points within them. Normally, however, the land use types in which such discounted random points have fallen should be noted together with their location, in order to provide a larger sample size for each land use type. This allows sufficient reserve points to be collected in order to ensure adequate coverage due to inability to reach a particular site, as to other unforeseen problems.

This type of remote sensing sampling strategy has the advantage that it could be easily adapted for use with most other forms of remote sensing imagery as well as orbital. Thus the proposed sampling strategy developed above and tested in the field (as described in chapters and) provides a reliable framework for testing the accuracy of any remote sensing image interpretation-based land use classification using the minimum number of points necessary, thereby saving time and money if employed in operational surveys where tight accuracy levels have to be guaranteed.

4.5.2.4. Size of sample point

Obviously the term sample "point" in this type of study is a misnomer because, even though the theoretical location of the sample site may be determined by the grid intersection, the practicalities of field work make it virtually impossible to locate and classify. Therefore, a selected area around the point must be considered and its actual size will depend on the scale and resolution of the imagery, the map scale and the purpose of study. Again, there appears to be little guidance in the published literature but it is generally accepted that the quadrat should not be smaller than the ground resolution of the system used. Consequently, in the case of LANDSAT MSS imagery the size of the objects in land use surveys should be greater than pixel size, i.e. greater than 79 m by 79 m.

Lietzke and Stevenson (1974) have reported that the "threshold of resolution is 10 acres (4.05 hectares) for comprehensive land use mapping and 2 to 5 acres (0.8 to 2.03 hectares) for some specific categories". No mention of mapping of imagery scale was given but, on the basis of this information, the minimum resolution, i.e. the smallest identifiable land use pattern would be an area equivalent to 200 m by 200 m or approximately 6 times the area of a pixel.

Joyce (1974) stated that "the minimum-sized unit area delineation of 40 acres (16 hectares) or larger is most common" and refers to research by Alexander (1973), Fizer and Brown (1973) and Hardy, Skaley and Phillips (1973). Consequently, it appears that the size of the sample "point" should fall between the resolution threshold (200 m by 200 m) and the minimum size area that can be delineated, i.e. 400 m by 400 m (16 hectares). Joyce did not state the scale but Hardy et al mentioned that "direct transfer may be made at ratios of 1:250,000 and 1:150,000 with map units of about 25 hectares (500 m by 500 m) and 10 hectares (100 m by 100 m) respectively for the purpose of this investigation a square of 250 m by 250 m has been adopted as the size of the sample point. More details on scale and resolution have been presented in Sections 4.2.4. and 4.2.5. respectively.

4.5.3. <u>Ground Data Acquisition</u>

As mentioned previously the correct selection of the variables which should be investigated in the field forms an important part of the overall ground truth procedure. The variables should represent the dominant factors that have affected the spectral nature of the image and the extent to which they should be recorded in the field is mainly a function of the scale and resolution of the imagery, the classification system and the purpose of the study.

The main variables that have been considered in small scale land use surveys have included soil, bedrock, vegetation, surface morphology, urban centres, water surfaces, slope and aspect. But, the appropriate level of measurement and/or description has not been adequately described and most guidance can be obtained by examining the data acquisition sheets devised for land use mapping from aerial photographs, e.g. Benson et al, 1971, terrain analysis studies, e.g. Mitchell, 1973, other closely related studies, e.g. Henderson's (1975) investigation of the role of radar in land use mapping or the more basic research oriented studies investigating LANDSAT MSS imagery (e.g. Curtis and Hooper, 1974). These sheets (see Appendix), at least, give some idea of the level of description at the particular scale that the researchers have decided to investigate.

Small scale land use surveys have had the constraints of the classification system super-imposed over the data collection techniques and this has controlled the extent to which data has been collected. Therefore, if the broad outlines provided by the U.S. Geological Survey Circular 671 are adopted then the variables should be measured or described in a hierachial manner to coincide with the various levels of the classification schema, e.g. Levels 1 to 4. This means that a satisfactory ground data sheet should be designed so that the information can be collected at different levels of sophistication but with an operational rather than a research bias. The extent and type of data collection in the field are largely influenced by time and cost factors and rigidly controlled observations which aid the very detailed analyses of spectral responses are not required.

The major factors to consider at Levels 1 and 2 are those which lead to the spectral responses on the imagery associated with broad categories of vegetation. These mainly include the distribution patterns of the vegetation and the colour of vegetation and soil associated with those patterns. Data may also be collected which coincides with the U.S. Geological Survey Circular 671, Levels 3 and 4. This permits the more specific identification of vegetation types at the sample point and their use may not be obvious during interpretation but the data may be helpful when trying to isolate reasons for mis-interpretation. For example, the seasonal variation in some types of vegetation may vitally affect the response recorded on the imagery.

Other factors which affect the spectral responses should be recorded, e.g. slope, vegetation spacing and height, colour of surface. Provision should be made for recording possible seasonal changes in vegetation characteristics at different levels as well as possible new development projects in the region which could cause discrepancies between the imagery and the data collection. Ground level photographs of the sites have been found useful in assessing mis-interpretation. In addition, vertical aerial photographs have been used by various researchers as an alternative method of establishing the accuracy of their interpretation of orbital imagery (van Genderen, 1973; Sweet et al, 1974).

The stages in the preparation for data collection and the associated field procedure will be described in detail in the next chapter.

4.5.4. Summary

The collection of information about selected variables at an appropriate level requires the development of an appropriate sampling design and ground data collection procedure which will enable the rapid collection of data to check the accuracy of interpretation and to help isolate possible reasons for mis-interpretation. Basically, this necessitates the selection of an adequate sampling strategy, optimum sample size, area of sample "points" and the development of an adequate ground data collection form and traversing procedure.

Investigation has shown that the most appropriate sampling strategy for this study is the stratified random techniques. However, no established method for determining the ideal number of sample points could be discovered and a special method has been developed to overcome this problem (see Section 4.5.?.?.). The size of the sample "point" was established after considering the minimum mapping unit and image resolution (see Section 4.5.2.4.). Detailed explanations of the application of these aspects in the operational sense and the development and use of a ground data acquisition sheet and field traversing routine are presented in Chapter 5.

4.6. GENERAL SUMMARY

The overall aim of this chapter has been to consider the main factors that affect the level of accuracy of the production of small scale land use maps from LANDSAT MSS data in order to assess the relevant approaches that have been utilised within a broad range of remote sensing techniques. In addition, it has brought together the results of many research projects which have focussed on specific problems that are applicable in the production of small scale land use maps. Consequently, the summary of techniques has permitted the evaluation and elimination of some methods and it has also allowed some procedures to be adapted and new ones to be developed so that the basis for a feasible methodology can be established.

It appears that the major problems to be investigated revolve around the selection of the most appropriate imagery format and scale, visual interpretation procedures, the development of a satisfactory classification scheme and the establishment of a viable sampling procedure for testing the results of the interpretation as well as locating possible reasons for mis-interpretation. The next logical step, therefore, is to test the most relevant techniques involved in each stage in the operational sense and Murcia province, South East Spain was chosen as the most suitable location. The results of these investigations are described in the next chapter.