Use of remotely sensed data for forest type mapping and inventory in north east Tasmania, Australia

By

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Statement

This thesis contains no material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

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Abstract

This thesis has developed a methodology for the extraction of landform and land cover information in complex terrain using Landsat Multispectral Scanner (MSS) digital data. As a result it has been possible to produce a forest inventory for the Scottsdale forestry district in north east Tasmania.

Considerable research has been directed towards the application of Landsat multispectral scanner data in the forest environment. To date, most of this work has been done overseas, and relatively few studies have been done in Australian forests. This thesis has reviewed most of this work, highlighting major deficiencies and accomplishments.

An important result in this study has been the extraction of useful information in complex terrain. Very few researchers have reported success in mapping land cover types in mountainous areas. This is mainly due to variations in facet slope and orientation which govern the radiant energy intercepted by individual pixels in the Landsat scene. As a result, cover types may have very similar spectral reflectances but quite different radiances due to the shading effect of topography. This makes the classification and labelling exercise difficult. Tasmania is a high relief area and an illumination model employing the logarithm of band ratios was used to account for topographic effects.

Ancillary data comprising district and forest block boundaries were integrated with Landsat data in the

classification and labelling of various forest types in the study area. A ground truth survey verified that the resulting land cover was being mapped within a satisfactory level of accuracy. The overall accuracy level was 89 percent, whilst for individual land cover types the accuracy level ranged between 37 to 96 percent.

Two Landsat scenes (1980 and 1984) were classified and labelled separately. These two scenes were resampled to a common base grid with a two second resolution. Spectral change detection methods and change detection based on two dates classification were analyzed. Temporal changes in the major land cover types were obtained by differencing the two classifications. The extent of these changes were calculated not only for the district as a whole but also for each of the forest blocks separately.

The methodology developed in this thesis is also applicable to satellite systems with increased spatial and spectral resolution. In particular, data from the Landsat Thematic Mapper, SPOT and MOS-1 create new and exciting possibilities for future work in remote sensing of forest resources. The increased spatial resolution of these satellites not only increases the potential for visual interpretation of the images, but as well should provide an improvement in the accuracy and detail of information provided by the classification techniques described in this thesis.

This study has clearly demonstrated the value of merging MSS data with ancillary data such as digital terrain and different administrative boundaries. Using these methods, a conceptual

information system for forest resources in Tasmania is also explored leading to specific recommendations for the form of an operational image base information system for forest resources.

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CHAPTER 1

SCOPE AND OBJECTIVES

1.1 INTRODUCTION

The need to improve the management of natural resources stems, in part, from the fact that many of these resources are no longer plentiful. In addition, many natural resources are obviously being degraded as a result of inappropriate human actions. Recent decades have seen increased public awareness and concern over the status of many natural resources. Against this background of depletion, degradation and rising public concern, it is not surprising that statutory agencies responsible for resource management have found it necessary to intervene in resource using activities. Such interventions have, as primary aims, improvement in the efficiency of human use of the resource and minimization of adverse consequences that often stem from resource using activities. An essential part of any resource management program is the acquisition of accurate and timely information about the characteristics and condition of the resource.

The above opening comments apply equally well to a range of natural resources including water, soil and forests. It is the forest resource that forms the focus of this thesis. More specifically, the thesis concentrates on the development of a reliable, timely, efficient and economic technique for identifying, classifying and mapping forest resources. The technique uses satellite information to meet these objectives. Before some of the more traditional techniques for assessing forest resources are discussed, it is appropriate to briefly set the study region in context.

As a continent, Australia is not noted for the magnitude of its forest resources. Within the country, most of the high quality forests occur in the southeastern and south western margins. The state of Tasmania where 40 percent of the land surface is forested is of major significance to national timber production.

Approximately, 2,214,000 hectares, or 32 percent of the total area is commercial quality forest (Tasmanian Year Book, 1986). Of this area 905,000 hectares are privately owned and 1,309,000 hectares are Crown owned commercial forests. Forestry and related industries are important employers in the state, supporting over 7000 workers. In 1981 the value added from forest products amounted to $279,000,000. The majority of forest products are sold outside the state and form an important source of income.

The history of forest utilization in Tasmania is long and complicated (Wood and Kirkpatrick, 1984). An early emphasis on sawmilling was augmented in the 1930's and 1940's by domestic fine paper and newsprint production. Later in the 1970's, woodchipping for export was rapidly developed. Land alienation has led to a significant area of the state coming under private ownership, although a large area including much forested land has been retained in public ownership as Crown land. The administration of this Crown land is the responsibility of the Department of Lands, Parks and Wildlife.

Responsibilities for forest management on Crown land are divided between the Forestry Commission, a state body, and two major companies which have long standing rights or concessions to large areas of forest. Over a lengthy period, state governments have adopted the practice of allocating long term rights over large areas of publicly owned forest to individual companies. In most cases the allocation has involved initial rights to a concession area followed by additional rights over the timber area in an adjacent reserve area if the company fulfilled certain investment obligations. Large volumes of timber are also obtained from private land where the long term management decisions are in private hands.

At present, a variety of techniques are used to assess forest resources in Tasmania. Approaches differ between the state body, the major forest based companies and small private concerns. In some areas there has been substantial investment in ground and aerial surveys. By contrast, economic and other considerations have left other areas unsurveyed. Patchy information obviously acts as a hindrance to statewide planning and also prevents comparisons between regions.

Within Australia, most resource information surveys still rely on traditional methods involving, for example, interpretation of aerial photographs and ground survey. Although forests often contain valuable resources, the per hectare economic return is generally quite marginal so that expensive ground and aerial survey is often difficult to justify. As a result, there are strong grounds for exploring the possibilities of using more recent remote sensing technologies to provide basic data. As is discussed in Chapter 2, many studies have shown that accurate information for large areas can be obtained quickly and at relatively low cost from satellite scanners. It is against this background that this thesis is set.

1.2 TECHNIQUES FOR FOREST INVENTORY IN TASMANIA

Forest inventory techniques used in Tasmania vary with the kind of forest and level of information required. Until the early 1950's, work concentrated on oldgrowth forests which are defined by age and structure. More specifically, they comprise forests which are over 120 years of age and which have uniform structural characteristics and no net growth. Inventories for oldgrowth forests estimated only sawlog volumes. As the demand for sawlogs grew in the 1950's, forest inventory was extended to cover regular regrowth forests. By definition, a regrowth forest younger than 110 years may be termed regular if it is even aged, that is, if it has regenerated from the same event, which is usually a fire. Attempts to measure changes in biomass led to the introduction of site index tables and yield tables. A site index table indicates the level of growth in a forest plot by measuring the mean dominant height of the tallest trees in a stand at the age of 50 years. A given site index is associated with an individual dominant tree height curve. This curve varies with age. Thus knowing the age of a plot and its dominant height, it is possible to obtain a site index. The total biomass is obtained from the yield tables which in turn depends on the site index and the age of the forest.

In the 1960's, attention turned to irregular regrowth forests characterized by trees of different ages. A new technique, the Continuous Forest Inventory System (CFI) was developed to handle both regular and irregular forests. Essentially, the CFI technique provides a very intensive monitoring of the vegetated environment for selected plots. All trees in the plot are surveyed for vital statistics. Such data as crown height, quality of trees, number of regenerated seedlings, and understorey vegetation are also recorded. In brief, the system gives an accurate and complete representation of the vegetation in the plot. Monitoring the CFI plots takes place five years after mutual establishment and every 10 years thereafter. Forest type maps, produced by interpreting vertical aerial photographs, form the basis of all forest inventories. In Tasmanian forests, eucalypt forests are segregated according to age class (oldgrowth or regrowth), height class or density class. It is these maps, showing a mosaic of forest types, which are the basis of stratification for inventory purposes.

Since the purpose of the inventory varies with forest type, the stratification procedure, sampling intensity and sampling design also vary. This is discussed separately in the following sections.

1.2.1 NATIVE FOREST ON CROWN LAND

In order to undertake forest inventory procedures systematically, the Forestry Commission has divided Tasmania into different Measurement Cycle Areas (MCA'S). Several factors were influential in delimitation of the MCA'S. For example, there was a need to ensure that these divisions coincide with concession areas; it was necessary to consider the types of forest (regular/irregular); and various management considerations had to be incorporated. Data collected at each MCA are then used for the CFI, site index or temporary plots surveys. The procedure is based on ground sampling within strata and substrata classified from photo interpretation maps. Different oldgrowth height classes form the first stratum for sampling. The strata are then further subdivided into substrata based on regrowth height classes. The total area within each substratum is determined, and permanent or temporary plots are established at selected sites. The substrata are sampled at the rate of two permanent plots per 500 hectares. For preliminary assessments aimed at establishing the quantities and types of timber available in an area, that is resource level assessment, rectangular plots covering 0.4 percent of an area are established. For more detailed management level information, strip lines are laid down and area is measured regularly on the equivalent of 5 percent of these. With both approaches, species, height, diameter and crown diameter obtained from the plots are used with the site index and yield tables to predict standing and future volume.

1.2.2 EXOTIC SOFTWOOD PLANTATIONS ON CROWN AND PRIVATE LAND

No aerial photography is used to classify softwood plantations which, in Tasmania, consist mainly of *Pinus radiata*. Rather, each compartment within a plantation is plotted on a map and its area is calculated using a hand planimeter. Information including species, year planted, site quality, stocking, and the thinning regime is recorded for each compartment.

The information is updated annually to include new planting, replanting, thinning and clear felling. Inventory estimates of standing volume are based on ground sampling within strata identified from the Plantation Area System (PAS). With this system, each plantation is subdivided by age, site quality, thinning regime and blocks etc. The areas for sampling are selected in the following order of priority:

- Stands likely to be clearfelled or thinned for which accurate volumes are needed for operational scheduling.
- Stands which are not yet ready for clearfelling but which will not be thinned again.
- Stands whose age, regime or site type are still inadequately sampled by PAS
- Any other stands except
    - Clearwood stands which have not had their final thinning/pruning
    - Stands younger than 10 years of age
    - Stands due to be waste thinned
    - Large areas of very poor stands which are unlikely to see operations in the near future (Tasmanian Forestry Commission, 1986)

Because of the uniform nature of softwood plantations, PAS plots do not require the same sampling intensity in operational level assessments as are required in native forests.

1.2.3 PRIVATE NATIVE FORESTS

Tasmania's private forests also play an important role in the economy of the state. During the period 1971-1981, private forests yielded approximately 40 percent of the pulpwood cut in the state and approximately one quarter of the total sawlog cut. Despite this obvious economic importance, no reliable and systematic inventory of private forests existed until very recently. Realizing this problem, the Tasmanian Forestry Commission and Private Forestry Council in 1978 decided to review, update and improve the assessment of the private forest resource. In 1984 a report (Tasmanian Forestry Commission, 1984) highlighted the following steps as necessary for assessing the private forest resource:

- delineation of private forest areas on aerial photographs,
- sample selection on aerial photographs and interpretation of forest types,
- sub-sample of photo plots and measurement of these on the ground to obtain correlation between volumes on the ground and volume estimated from photo interpretation.

This type of classification, developed to minimize costs, is obviously less intensive in nature than the classification for the Crown forests discussed previously.

For the state as a whole, then, there are different systems of forest inventory for native forests on Crown land, *Pinus radiata* plantations on both Crown and private land, and for native forests on private land. As mentioned earlier, the intensity of the survey varies with the nature of the forest: whether it is old growth, regrowth of a regular nature, or regrowth of an irregular nature.

The survey process in itself is a costly exercise. It is estimated (Gordon, 1986, personal communication) that each survey of a permanent plot as used in the CFI costs approximately $1000. A survey of a temporary plot costs $ 500, whilst plots used in applicational assessments are much less expensive. The costs and manpower constraints naturally impose limits on the frequency of the observations which, as mentioned earlier, varies at either 5 or 10 year intervals in the use of the CFI.

Land use modifications which may occur at higher frequencies are assessed on an individual basis, that is, a known change in a given region is monitored by aerial and ground surveys. The technique does not account for inadvertent modification caused by some environmental change or deterioration. Examples of this effect would be forest damage as a result of disease, frost, fire or drought. Clearly a wider regional survey at frequencies greater than five years would be beneficial.

There is a great difference between surveys undertaken in private and Crown lands. Despite the importance of private land to the forest industry of the state, most of the intensive monitoring of the forest resources has been restricted to Crown land. Therefore, it would be beneficial to provide basic survey data for these regions coupled with information on temporal changes.

From the above, the picture emerges as one in which basic forest inventory data is variable in quality and quantity, and variable and sparse in time and space. It is within this context that the feasibility of a remote sensing system must be examined.

1.3 POTENTIAL APPLICATIONS OF LANDSAT DATA TO FOREST INVENTORIES IN TASMANIA

From the preceding discussions, it is evident that there is a variety of Tasmanian forest classifications and that they are characterized by differences in detail, resolution and temporal and spatial coverage. Given this, it is worthwhile to examine the possible usefulness of a rapid and low cost classification based on satellite data.

The satellite in question is Landsat, a polar orbiting satellite which maps Tasmania and most of the world every 16 days at a nominal altitude of 705 kilometers. In addition, the satellite is sun-synchronous, passing over the state at approximately 9.45 am Eastern Standard Time (23 hours 42 minutes and 36 seconds GMT time). Information is gathered by the satellite scanner in four bands of the solar spectrum at a nominal resolution (the capacity of a remote sensing device to register detail of an object), or pixel of 59 x 79 meters. Further information on the Landsat system is provided in Appendix A1.0.

Temporal coverage at a 16 day frequency is useful in agricultural applications where monitoring of crop growth over short time periods is needed (Swain and Davis, 1978). In forest inventory applications, it would seem that several observations a year would be sufficient to satisfy most needs. In fact, the Tasmanian environment features a high frequency and extent of cloud cover, so that in general three or four cloud free Landsat coverage per year is the best that could be expected in many parts of the state.

The spatial resolution of Landsat MSS data imposes some significant constraints in its application to forest studies. Due to its low resolution, finer structures which are so important for the recognition of forestry data in ordinary photos are lacking. Despite the low resolution, however, it is possible to notice targets smaller than the resolution element (Lillesland and Kiefer, 1979). Roads, boundaries, water reservoirs etc. may provide a reflectance that will contrast sharply with their surroundings.

Given the low resolution of Landsat, it is evident that it cannot replace detailed forest photo interpreted maps. Data for the continuous forest inventories in Tasmania are based on high resolution (1:15 000) aerial photographs which are used in stereo pairs to maximize the amount of information gained from the images. Similarly, dependence on ground surveys and/or aerial photography applies to other forest survey techniques practiced in the state. Within this context Landsat data should be viewed as separate and complementary to these techniques since Landsat can provide consistent and very wide area coverage of vegetation types at a very economical rate. For example, it is estimated (Lillesand and Kiefer, 1979) that more than 1600 aerial photographs at a scale of 1:20 000 are needed to cover the 185 km^2 area contained in one Landsat image. Moreover, in areas where no aerial photography is available Landsat may serve as an important tool at the exploratory or inventory level, especially as a basis for further planning of aerial coverage in the areas which appear most promising areas for forest development. In other cases it may serve to complement inventories or reconnaissance surveys where small scale photography is also used.

The degree of vegetation detail contained in a Landsat image is, to a large extent, dependent on the characteristics of the soil, vegetation and the atmosphere at the time the image was taken. At the very least, and with a minimum of computation, these data may provide broad classification types (eucalypt forest, rainforest, grassland etc.). Further image processing may yield subdivisions within such basic types. Indeed, one of the main objectives of this thesis is to explore the extent to which forest features may be discriminated using Landsat data. This is a task which has not been previously undertaken in the context of Tasmanian eucalypt forests.

Probably the most outstanding feature of Landsat data is its digital data base. Each resolution element is assigned four numbers representing the reflectance of solar radiation in four wavelength bands. Using statistical techniques, it is possible to register each resolution element to map coordinates with a locational error corresponding to a fraction of a pixel. This powerful feature of the Landsat system enables the very rapid and efficient computation of total area coverage of forest types and their accurate representation in a cartographic form. Forest cover in many real world situations may consist of small and irregular plots dominated by identifiable vegetation types. The Landsat digital technique, provided that it has sufficient capability for discrimination, is best suited for the acquisition, analysis and display of this kind of data.

Probably the most important application of Landsat data is in mapping forest cover changes over time. This is accomplished by analyzing different satellite images taken at different times (see Chapter 6). The smallest changes detectable and the accuracy of their positioning are of the same magnitude as the accuracy of pixel registration between images. This is a very satisfactory resolution and positioning error considering the regional coverage of one Landsat scene (185 x 185 km). In fact it is difficult to find any other system that could match the speed, efficiency and cost effectiveness of Landsat data in determining initial land cover changes over regional areas. Once areas of change have been determined, photography and ground surveys can be used to explore the nature of the changes in more detail. At present the technique is being used throughout the world to monitor resources over large areas. This issue is explored in more detail in Chapter 2.

Despite the low resolution of the Landsat Multispectral Scanner (MSS) data, the spectral information contained in the four wavelength bands may be exploited to gain information not normally discernible from Landsat hard copy prints or from ordinary black and white aerial photography. Even if the feature being investigated is typically less than one pixel in size, its reflection pattern may be anomalous enough to indicate its presence in the pixel. In these kinds of applications, it is important to show a 1:1 correspondence between the anomalous signal and the feature being investigated. Therefore, there is need for reliable ground surveys to provide "calibration" of the Landsat signal. Thus, analyses such as these may provide information on such sub-pixel features as diseased vegetation, ground cover type at the forest floor, or level of forest regrowth.

Complex topography may be regarded as one of the greatest obstacles in the development of a Landsat based forest inventory. The problem arises because some surfaces are in shadow, protected from direct radiation. Conversely, north facing slopes receive more solar radiation than other surfaces. As a result, the radiance field as seen by the satellite may be very complex and this may hinder the classification process. In this thesis, a methodology is developed to filter out the effect of topography on the observed radiance from the Landsat image. The procedure followed and processing details are discussed in Chapter 5.

Landsat data may also be used as an input to a Geographic Information System (GIS). This technique is now gaining wide popularity in forestry applications where layered data from different sources such as satellite, aerial and ground surveys, geology, soils, terrain elevation, slope, aspect and land ownership are used for planning and management decisions. Chapter 2 details successful uses of this technique in various resource inventories which then enable better planning and management. In these cases satellite data is considered important in improving data resolution and feature identification. More significantly, in many cases satellite data is the only practical and economical means of regularly updating the data base. Various questions related to the use of remotely sensed data base as an input to a GIS are addressed in Chapter 3.

1.4 OBJECTIVES OF THE STUDY

The major objectives of this study are:

1. To develop an approach to, and evaluate the feasibility of, using computer-aided analysis techniques in identifying, mapping and determining the areal extent of various forest cover types in mountainous regions in Tasmania.
2. To develop a Landsat data based methodology for determining land cover changes over time.
3. To carry out quantitative accuracy assessments of a Landsat based land cover map and to determine the level of detail in terms of forest cover types that can reliably be obtained from Landsat MSS data.
4. To demonstrate the potential of Landsat and digital terrain data as an input to a Geographic Information System (GIS) based on remotely sensed data.
5. To provide decision makers with details of the data and methodology involved in merging and registering Landsat spectral data with digital topographic data and administrative boundaries.

1.5 THESIS OUTLINE

This Chapter has outlined the various Tasmanian forest inventory techniques and the possible role of Landsat data. Chapter 2 reviews the literature on the use of remotely sensed data for land use/cover mapping and temporal changes. In Chapter 3, the potential of remotely sensed data as an input to a GIS is explored by merging Landsat data, digital terrain data and different administrative boundaries. A conceptual information system for forest resources in Tasmanian is also discussed. Chapter 4 describes the location and boundaries of the study area. The physical and human characteristics affecting the landscape of the study area and which, in turn, form and determine the patterns on Landsat imagery are discussed. In Chapter 5, the concept of land use cover classification using Landsat MSS data, and details of the remotely sensed data and image processing system used are discussed. Landsat image classification and a data extraction technique using landform information and ancillary data are also discussed. Chapter 6 reviews various techniques presently used for monitoring temporal changes. Spectral change detection methods and change detection based on the classification of two dates of images, and their application to north east Tasmania are analyzed. The results of land use/cover inventories and changes over time in different forest types in the district are also presented in this Chapter. The summary and conclusions of the research project are presented in Chapter 7.

CHAPTER 2

REMOTE SENSING OF FOREST INVENTORIES --- A REVIEW

This Chapter concentrates on the application of Landsat data with special emphasis on forest inventories. The literature review reported in this Chapter has been subdivided into four components: visual assessment, computer aided analyses, accuracy assessment and the application in developing Geographic Information Systems (GIS) for use in forest resource assessment. Details on the theory of remote sensing, the mechanics of satellite images recording, its analysis and interpretation are outlined in Appendix A1.0.

2.1 REMOTE SENSING TECHNIQUES APPLIED TO FOREST INVENTORIES

2.1.1 INTRODUCTION

Any discussion of remote sensing of forest inventories must include other data types and methods of interpretation which do not rely on digital techniques. These involve mainly the use of aerial photographs. Cameras and films have been used for forestry work long before remote sensing became a commonly used term. This may be because remote sensing is often associated with the development of sophisticated electronic sensors which require computer manipulation of digital data. In remote sensing terminology, a photographic system consists of a camera to focus light energy directly onto photosensitive film. In general, these systems have very good spatial resolution characteristics, thus enabling aerial photographs to supply a clear and finely detailed picture of the environment. But these systems lack the broad spectral sensitivity obtainable with other sensors which have comparatively poorer spatial resolution characteristics. Lillesand and Kiefler (1979) pointed out that there are many non-photographic systems and some photographic systems which are quite complex optically, mechanically and electronically. Their power, space and stability requirements may be restrictive, often dictating the type of platform (or vehicle), from which sensors can be operated. Platforms can vary from stepladders to space stations. The cost involved in the acquisition of remotely sensed data depends on the sensor/platform combination needed in a particular application.

In contrast to the aerial photographs, scanners allow fine spectral data to be collected in a form which can be easily input into a computer. Images from a scanning system are derived when the light energy is recorded by sensors and recorded electronically as digital, or numeric data. The digital data may be converted back into illumination levels, thus allowing the information to be displayed as an image. The image can in turn be interpreted much like an aerial photograph. From the high altitude vantage point, satellite sensors such as Landsat MSS offer a synoptic view of very large areas. This allows the analyst to view an integrated picture and facilitates the sampling of an entire area, reducing bias resulting from an inadequate sampling size. The SPOT satellite launched on February 22, 1986, now offers imagery with the same spatial resolution as high altitude aerial photographs, with pixel size of 10 meters in panchromatic mode and 20 meters in MSS. But above all, the major advantage of satellite based sensors, whether they be cameras or electronic sensors, is their cost savings because they are continuous surveillance systems. In contrast aircraft surveys are usually done on a once-off basis.

2.1.2 LANDSAT MSS DATA FOR FOREST CLASSIFICATION

In forestry, research into satellite based remote sensing has been focussed so far on two applications:

1. The use of visual photo-interpretation techniques in association with hard copy Landsat imagery, and
2. The use of digitally recorded data which is analyzed by computer based classification techniques.

Relatively little work has been done using either of these techniques in Australia (Skidmore et al., 1986). Most of the reported work using Landsat MSS data has been applied either in the United States, Canada or Europe. Despite the obvious differences between the physical environment of Australia and these countries, their approaches to remote sensing problems may be of local relevance. Therefore, their literature is reviewed below.

In the following sections both visual and computer aided digital techniques are reviewed and discussed in the context of general land use/cover mapping and monitoring of temporal changes. Other topics discussed include the use of remotely sensed data as an input to a Geographic Information System (GIS) and the accuracy of Landsat MSS classifications.

2.2 VISUAL INTERPRETATION OF LANDSAT IMAGERY

These techniques involve interpretation of electronically reconstituted photographic products which are produced either in the form of individual band paper prints or colour composite images. Many studies involved mapping land use/cover. In forestry work, it is obviously important to differentiate forested from non-forested areas. It has generally been observed that only Level I land cover information can be obtained from visual interpretation of Landsat images (for description of Level I see Appendix A2.0). Thus, it is possible to differentiate forested areas from other broad categories, but in most cases, very little success has been reported in differentiating categories (such as communities) within forests.

Generally, to differentiate various land cover classes using visual techniques, reliance is placed on the colour, density, texture, shape and pattern formed on the images. Satisfactory Level I classifications have been reported by Heath and Parker (1973) and Woldai and Vermeer (1979) for general land use; by Eller et al. (1973) in separating forest and non-forest categories in Minnesota; and by Morain et al. (1977) for compiling information on vegetation and land use patterns in New Mexico. Katti et al. (1981) in India reported successful classification of major land units and land features such as forested areas, water bodies, different soil groups and geological features. Deciduous forests were also further differentiated. Similarly, other researchers reported success in further partitioning the classification of forest land. In the northern hemisphere, Eller et al. (1974) reported that he was successful in differentiating hardwood from conifer forests. Similar classifications have been able to distinguish burnt forest areas (Hathout, 1980), as well as logged and regrowth forest (Howard, 1976 and Jaakola, 1976).

In India, Unni et al. (1985), developed a fairly detailed classification for vegetation. It was based mainly on vegetation density (frequent opening, sparse vegetation, clear felled area, etc.) However, in a different region of India, Roy et al. (1985) using false colour composite images reported successful mapping of tropical evergreen and temperate forests. However, no success was reported in mapping semi-evergreen, subtropical broad-leaved forests and bamboo barkes.

In Australia, Jones (1976) was able to classify several categories of land which included rainforest, wet sclerophyll forest, dry sclerophyll forest and other non-forested classes. Laut and Nanninga (1985) reported successful differentiation of six basic components of the vegetative cover by colour, tone and texture on false colour composite images. These categories include closed forest species, eucalypt, non-eucalyptus, non-closed forest species, grasses, burnt land and bare lands. They reported problems in consistently identifying different types of grasslands in their study area without reference to ancillary information.

Landsat images have also been frequently applied to monitor the progress of forest operations, because logging activities have very sharply defined boundaries which can be visually identified

Zsilinsky (1973); Murtha (1973); Lee (1974); Lee et al. (1974); Lee (1975) and Murtha and Watson (1975). These authors mostly used Landsat images at various spatial scales and applied colour enhancement techniques to sharpen the contrast between the cleared and forested land. A different technique has been used by Oswald (1974) who examined sequential images to very closely monitor harvesting operations. Added features that could be distinguished were evidence of fire (Murtha, 1973) and regeneration (Zsilinsky, 1973).

Satellite images have also been used to map and assess the direction and magnitude of temporal changes. Generally, temporal changes are obtained by analysis of two or more separate images. This change determining process describes over time shift of one land cover class to another. In China, Welch and Pannell (1975) supplemented Landsat images with world war II vintage maps and aerial photographs to determine temporal land use changes in four big cities. Using individual bands and colour composite images they reported that the tonal or colour differences, in combination with spatial patterns and important supplementary information provided by development plans, permitted the different urban land use classes to be rapidly delineated. In Tasmania (Australia) Kirkpatrick and Dickinson (1982) reported the superiority of band 7 over colour composite images in discriminating agricultural land from native vegetation. From a 1: 250 000 scale map of a base image they traced the boundary between these two categories. By superimposing the base image over other images, they reported a significant shift from native vegetation to cleared land. Crapper and Hynson (1983) used positive and negative transparencies at the scale of 1: 100 000 to identify changes in urbanization and vegetation changes caused by recent fires and forest clearing operations.

In the Cholistan desert, Pakistan, Sanjrani et al. (1982) used Landsat data, ground surveys and aerial photographs to monitor changes in vegetation, soils and sand dunes. Similarly in India, Gupta and Munshi (1985) used three false colour images taken in different years (1973, 1977, 1980) to monitor land use changes. Four broad land cover classes were considered, namely forest land, arable land with habitation, water bodies and other areas. They reported its efficacy for monitoring the land use changes over a larger geographical area.

There have been few attempts to estimate the accuracy of visual interpretation techniques recorded in the literature. The general tendency is to visually compare results with aerial photographs. A more quantitative technique involves the use of planimeters and dot grids. However, Lee (1975) pointed out that, ideally, acreage determination should be done by overlaying the maps in a grid format on a digitizing machine. Lee (1975), Morain and Klankansorn (1978) and Bejarano and Okoye (1979) used planimeters and dot grid count methods to enumerate areas which were forest, non-forest and cleared.

A few researchers have conducted ground surveys to evaluate their classification results (Heath and Parker, 1973; Katti et al., 1981; Younes et al., 1982). They reported that visual interpretation of Landsat images yield only very general results. In Mexico Morain et al. (1977) and in India Unni et al. (1985)

and Roy et al. (1985) also made ground visits to check map accuracies and to label various land cover classes. Some researchers have evaluated their classification results by comparing them with ancillary information contained in reports and maps (Woldai and Vermeer, 1979). In Canada Hathout (1980) checked the accuracy of a Landsat classification map by using the method developed by Genderen and Lock (1977). For each land cover category they selected a sample between 15 and 32 points randomly selected from coordinates of a grid placed over the Landsat map. Deciduous and coniferous forests classified with an accuracy of 84 percent and 87 when compared with a vegetation type map. On the other hand they reported problems in differentiating grassland, shrub land and marsh land using a colour density slicing technique.

In conclusion, although visual techniques are relatively inexpensive and easy to use, their resulting classifications are crude compared to the computer aided classifications. On the positive side, they are easy to acquire and do not make great demands on the skill of an interpreter. However, there is a general lack of hard core data with which to evaluate such techniques. This is mainly because of the subjectivity of the method used and the consequent inability to quantify the boundary decision making process.

2.3 COMPUTER AIDED ANALYSES AND INTERPRETATION OF LANDSAT DATA

2.3.1 INTRODUCTION

Although visual interpretation of Landsat imagery gives the user a broad overview of the study area, computer aided classification using digital data stored on computer compatible tapes is generally considered the most accurate approach to classification and mapping. This is mainly because these techniques employ a large number of grey levels in each channel. These are amenable to statistical and mathematical manipulation. Secondly, digital techniques enable scene contrast or edge enhancement. Finally, computer based classifications are considered better because of their sophistication, achievable accuracy, better use of subtle differences in image colour and tone, compared to visual estimates where the decision to classify is based on context, shape and colour (Hoffer, 1979).

The crucial element in these digital techniques is the development of training sets which are related to reflectance values of the various land cover types. The literature reveals that supervised and unsupervised techniques or a combination of the two (called multi-cluster block techniques) are the most commonly used to define training area statistics. In the supervised training technique, the analyst identifies a region in the image for which the various cover types of interest are already known. In the unsupervised technique the analyst specifies the total area to be classified and the number of spectral classes required. The multi-cluster block technique can then be applied to several relatively small blocks in the data, each of which contains several cover types and spectral classes. Each data block is individually clustered, and then the spectral classes for all clusters areas are combined, through a series of man/machine interactions, to form a single data deck of training statistics.

A review of the literature revealed that supervised classification is the most frequently used technique. However, the choice of a technique is not only dependent on the nature and quality of the data available but also heavily dependent on the spatial and spectral complexity of the area and cover types involved. Fleming and Hoffer (1977) evaluated the use of different training area selection techniques. They concluded that the method used in developing training statistics may have a significant impact on the accuracy, manpower and computer time required, and the general success of the classification. These conclusions are supported by Camara (1981), who has given a critical review of the various approaches used in selecting training areas.

In summary, it seems that the results of most remote sensing projects are dependent upon the condition of different land cover classes, season and the processing technique applied. Both single and multi-date images have been employed for land use and vegetation type mapping at various scales of information. Anderson et al. 1976 described two levels of classifying land cover. These are referred to as Level I and Level II and are detailed in Appendix A2.0. A finer level of detail, Level III, may be defined for specific applications as required.

2.3.2 LAND USE/COVER AND VEGETATION TYPE MAPPING

Various researchers (Kirvida (1973); Hoffer et al. (1974); Heller (1975); Driscol and Francis (1975); Hoffer (1975 a, b); Schubert et al. (1977); Mckeon et al. (1977); Reeves (1978); Cannon et al. (1978); Jupp et al. (1979); Roller and Visser (1980); Prapinmongkolkarm et al. (1980); Adomeit et al. (1981), and Laut et al. (1985) have reported their experiences in mapping Level I land use/cover classes by using supervised, unsupervised and hybrid classification techniques. One example of a hybrid technique is given in Reeves (1978) who mapped land cover using a system called procedure I. Reeves used an array of individual pixels of known cover types to seed a clustering processor. In turn, the clustering processor defined the training statistics for various cover types (i.e. rangeland, forest land, non-forest land and water bodies).

Modified cluster block techniques have also been used to derive training set statistics (Fleming et al., 1975; Hoffer et al., 1974; Fleming and Hoffer, 1977; Bonner, 1982). Generally they reported a high level of accuracy in the classification process.

Some researchers have discussed their results in mapping Level II and Level III vegetation types. Vegetation types are more difficult to differentiate compared to broad land cover classes. This is because the reflection process from a vegetated surface is a complex one, involving radiation reflection from the surface, canopy and understorey. In addition, different vegetation types may have the same phenological characteristics.

Hoffer et al. (1974); Heath (1974); Krebs (1976) and Hoffer (1976) have differentiated major forest types such as deciduous forest, coniferous forest, deciduous cut over, aspen spruce, pine regeneration and grassland in mountainous areas without accounting for variations in spectral response due to topography. The accuracy level for these classes ranged between 74 and 85 percent.

Similarly, in Queensland, Australia, Hill and Hornibrook (1981) assessed the usefulness of Landsat data for broad scale land cover mapping and identification of major communities (Level II) within a region of complex vegetation structure. They reported that Landsat based Level I classification provides more accurate estimates of the extent of forested country than existing land use maps. Their results with Level II classification suggested that Landsat data can be used to define the distribution of specific mixed communities at a large scale. Laut et al. (1985) produced structural vegetative cover map for part of the Kakadu National Park in Northern Territory, Australia. Using a supervised maximum likelihood classifier, they reported that for an area which is isolated and of limited accessibility, Landsat can provide an excellent overview of the pattern of vegetation for such type of area. Justice and Townshend (1980) compared Landsat based classification results with the ground data obtained from aerial photographs using a stereo-facet plotter. He reported an overall accuracy level of 85 percent, whereas for more complex mountainous areas the reported accuracy level was 65 percent.

Working in a Mediterranean environment, Townshend and O'Justice (1980) applied a monocluster block unsupervised classification technique. This technique involves combination of several heterogeneous blocks and then clustering the entire group as a single unit. A similar hybrid classification technique was applied by Rohde (1978), Fox and Myer (1979) and Nelson and Hoffer (1980).

Among other techniques, Hass et al. (1983) applied principal component analysis (PCA) to classify and map vegetation. Using scene brightness and greenness, they identified and mapped eleven land cover and natural vegetation classes. They reported that PCA can effectively be applied for mapping general vegetation types over large areas.

In Alaska, Miller and George (1980) used the ratio of Landsat band 7 to band 5 (the greenness index) as a tool to map different vegetation types. No quantitative evaluation of the results was conducted but they reported that the results were qualitatively acceptable.

Sadowski and Danjoy (1980) working in tropical South American rainforests, compared Landsat data with radar and aerial photography. They concluded that Landsat and radar data can provide information to aid first order stratification and classification. Such first order surveys can delineate forest areas from most non-forested areas and may help further stratify forest classes according to landform, drainage condition and tree density.

2.3.3 VEGETATION TYPE MAPPING USING IMAGES FROM DIFFERENT SEASONS

The spectral characteristics of vegetation are time dependent. Some vegetation exhibits significant changes in its reflectance properties from one season to another. This in turn causes changes in image signatures. Realizing this phenomenon, many investigators have tried to separate different types of vegetation using images from different seasons. For example, Borden _et al_. (1974) analyzed summer and winter data separately and in combination so as to differentiate various land cover types such as hardwoods, conifers, hemlock hardwood, fields and water. They concluded that these types can be differentiated with 98 percent accuracy. In addition, they observed that clear cut areas of more than 12 hectares can be easily detected by computer processing.

Williams (1976) and Kourtz (1977) also used winter and summer Landsat data to differentiate pine plantation from hardwood. Williams (1976) reported winter data more useful for this purpose, whilst Kourtz (1977) stated that the winter data provided a great deal of information on coniferous density and age class. Williams (1976) also reported that all categories of interest could be defined when summer and winter data were combined. Taking advantage of seasonal changes in sun angle and vegetation cover, they reported that hardwood could be separated from pine most effectively on winter data; stand density could be defined better on summer data when the sun angle is high; and that regenerating and clearcut areas could be defined on both data sets.

In Canada, Kalensky and Scherk (1975) examined the applicability of using multi-date Landsat imagery to delineate and identify coniferous forest, deciduous forest and non-forest land. They reported an accuracy of 83 percent when multi-date classification was used. By contrast, the classification accuracy for single date analysis varied significantly (67 to 81 percent) as a function of the date of the image acquisition. Kan and Dillman (1975) also analyzed various seasons of Landsat images and reported that temporal analysis improved classification accuracy by 11 percent. An accuracy as high as 79 percent was obtained for classification of softwood, hardwood and regeneration vegetation types.

Some other researchers (Omakupt and Vunpiyart, 1980; Harrington, 1981; Kalensky, 1974; and De Gloria et al., 1975), reported the use of single and multi-date data to differentiate very broad land cover types like agricultural crop land, fallow land, range land, bush land, grassland, forest land, urban land and water bodies. They all reported good results with multitemporal images since the accuracy level significantly increased when the phenological characteristics were taken into consideration.

In northern Italy, Lapietra and Megier (1976) used Landsat data to estimate the area of poplar plantations. Using single acquisition four channel data they achieved an acreage estimation accuracy of 80 percent. The accuracy level increased to 95 percent when three acquisition (12 channels) data and Principal Component

Analysis (PCA) were used. Reeves et al. (1977) in Texas, undertook a study to map and enumerate acreages for pine forest, hardwood, rangeland and mixed forest for different counties. Using May and November Landsat MSS data, they applied a training field classification approach. A difference of 10 percent was obtained in the May classification when the aggregate of all counties was compared with other surveys. Differences greater than 10 percent were obtained with individual county classifications. Mukai and Takenchi (1979) also used multi-temporal Landsat data to determine the biomass of agricultural crops and forested areas. Their supervised classification technique allowed an accuracy of 80 to 90 percent for pine, cedar and broad leaved trees. Total timber volume was estimated to 80 percent accuracy.

2.3.4 TEMPORAL CHANGES

The ability to detect temporal changes in land cover type, and its condition, is extremely important for effective management of land resources. Various land cover types exhibit different characteristics in their life cycle and, overtime, their spectral signatures change significantly. The advent of satellite sensors, providing repetitive coverage over the same area enabled many researchers to monitor temporal changes.

There are six frequently used techniques for detecting change using remotely sensed data. They involve either a post classification comparison, an image differencing (delta change), the albedo differencing, a change vector analysis, the layered spectral/temporal change detection or a principal component analysis (PCA) based change detection technique. A brief description of these techniques is given in Chapter 6.

De Gloria et al. (1975) examined the role of aerial photographs and Landsat multi-temporal data in mapping and quantifying changes on a seasonal basis. Using discriminant analysis they reported that various land cover types (ephemeral vegetation types, surface water, upland shrub types and snow) can be mapped very accurately. In British Columbia, Lee et al. (1977), using summer data from different years and applying supervised classification, reported changes in clear cut and burnt areas. Weismiller et al. (1977), designed and evaluated different computer based change detection techniques along the Texas Coast.

To evaluate the performance of the various techniques, comprehensive ground data were required. In the absence of such data they used the post classification comparison as a standard to evaluate the results from the three other techniques. They concluded that the techniques using spectral/temporal change and delta changes agreed with the post classification comparison. However, many small areas of change were not identified. Major discrepancies existed between the post classification and the spectral/temporal change detection results. This work is further discussed in Chapter 6.

Other researchers like Rubec and Thie (1978), Wickware (1979), Joyce et al. (1980), Wickware and Howarth (1981) and Howarth and Wickware (1981) used the post classification change detection technique. Joyce et al. (1980) used the above technique as well as the logical pattern technique to detect and monitor changes in land use over a period of five years. The former technique simply compares the classifications at the beginning and end of the time study. The latter technique produced five classifications using Landsat data for different seasons throughout the 1973-1978 time period. The sequence of land cover classes was examined for each pixel location to determine whether the sequence showed a logical change pattern as defined by various input criteria. They evaluated the two techniques by comparing their estimates of forest change with similar estimates using colour aerial photographs. A field examination was made on locations where the two data sources were not in agreement.

In Canada, Howarth and Wickware (1981) outlined and discussed the methodology to monitor vegetation changes by applying post classification change detection and band ratioing techniques. In the ratioing technique, the intensities of reflected energy recorded in one band for the pixels of one Landsat scene are divided by the intensities in the same band for the other scene. The data are then compared on a pixel to pixel basis. The changed areas are detected by examining the changes in the intensity of reflected energy. Band ratioing was also reported by Wilson et al. (1976) for land cover change detection.

In Australia, Byrne et al. (1980) used multitemporal Landsat data to detect land cover changes in the Batemans Bay area of New South Wales. They reported that the PCA technique effectively enables the analyst to map cloud covered and cloud free areas, highlighting changes that have occurred in cloud free areas. In another study Byrne et al. (1980) superimposed two four channel Landsat scenes of the Bateman Bay area, which were recorded on different dates, and treated them as a single eight-dimensional (channel) data array. They reported that the PCA of this array resulted in the gross difference, associated with overall radiation and atmospheric changes, appearing in the major component channelsMinor changes associated with local changes in land cover appeared in the minor component channels.

2.3.5 **SUMMARY**

From this examination of the literature, it is clear that computer based digital techniques are becoming increasingly popular. Amongst the various classification techniques, supervised, unsupervised and the combination of the two are preferred in land use/cover and vegetation type mapping. Some authors claim to achieve better results with a supervised classification technique because it is easier to delineate well defined classes by supervising the computer. This however, requires extensive familiarity with the study area and the classes to be distinguished. For large and complex areas most researchers use unsupervised classification techniques, especially if the degree to which various forest types can be distinguished or the factors which affect classification results are to be determined.

The review of the literature also showed that computer aided techniques have been used efficiently and accurately (85-95 percent) to provide and update Level I and Level II information on land cover. The techniques should prove useful in the

Tasmanian context because they could fill the existing data gaps, especially in private forests. Similarly, resource information of Crown forests could be updated frequently and at economical rates.

Experience has shown that there is usually some resistance to the introduction of new technology. As Krebs (1982) pointed out, when a new technology applicable to resource management is introduced, it goes through three phases. It is first attacked, then ignored and then accepted after the applications and benefits are recognized. It may be agreed that satellite remote sensing is going through the same cycle and is at the first stage. Various questions regarding its potential and the products obtained from it, are being asked. In many cases, these questions stem from unrealistic expectations of the potential of Landsat data, and are followed by disappointment.

The forest manager must be aware that, like other systems, there are limitations and that seldom is any one system the total solution to management problems. For example, aerial photography is certainly a better surveying tool in detailed inventory work at scales of less than 1: 25 000. However, repeated coverage of a large area is not only expensive but also time consuming. Although the spatial resolution is moderate, the Landsat satellites can map large areas at frequent intervals, thus offering a unique capability to monitor changes at a macro level. Such systems as the Thematic Mapper and SPOT data with a 30 and 20 meters resolution respectively have the potential to provide much finer information than the Landsat MSS data, but at proportionately greater cost.

A blending of mutually supporting systems should always be considered. A more rational approach in deciding which system to use is to determine firstly what the objectives of a project are and secondly what sort of information is required? The various systems offering the required information should then be evaluated in terms of trade off between cost, accuracy, and efficiency.

2.4 ACCURACY LEVEL ASSESSMENT

Most Landsat classification studies rely on ancillary data, obtained from either ground or aerial surveys, to test the accuracy of the classification. Mueller-Dombois and Ellenberg (1974) and Mead and Meyer (1977) have discussed various approaches used in ground reconnaissance surveys of Landsat classifications. There is need to test the techniques for determining the accuracy of the classification in a wide variety of environments and at different times. Current assessment techniques need to be clearly understood before being applied.

Several different qualitative and quantitative techniques have been developed and used to evaluate computer based classification results. Qualitative evaluations of the classification results can be obtained by visually comparing the classification with an existing map. Although this is a subjective technique, it does provide a rapid and simple estimate of the classification accuracy. The quantitative evaluation techniques however are more objective.

The most common quantitative way to describe the accuracy of a Landsat image is in the form of an error matrix (e.g Todd et al., 1980; Mead and Meyer, 1977; Hoffer, 1975). An error matrix expresses the number of pixels assigned to a particular land cover type relative to the actual land cover as verified in the field or from photographs. The columns usually represent the ground truth and the rows indicate the computer assigned land cover category

$$\begin{bmatrix} n_{11} & \vdots & n_{1p} \\ \cdots & n_{ij} & \cdots \\ n_{p1} & n_{pj} & n_{pp} \end{bmatrix}$$

The total number of pixels correctly classified (Y) can be described as:

$$Y = \sum_{i=1} n_{ii}$$

The use of an error matrix provides an effective means of evaluating errors when a pixel is assigned to the wrong class (commission error), or when it is omitted by the classification procedure from the correct land cover (omission error). A perfect classification would result when only the diagonal terms are non zero. That is, the incorrectly classified pixels would be described by

$$n_{ij} \neq 0 \quad \text{when } i \neq k$$

This matrix allows the analyst to determine the performance for individual categories as well as for the overall classification (Hoffer and Fleming, 1978).

Accuracy assessment techniques can be non-site or site specific (Mead and Szajin, 1981). Non-site specific accuracy is usually expressed as the similarity between the total area in each land cover type as determined by a Landsat classification compared to the corresponding area determined from measurements in the field or from photo-interpretations. The non-site specific method compares only total area without regard to location. Site-specific accuracy, however, considers the spatial nature of the data, therefore it is more informative. In this case, two spatially defined data sets (one being ground truth) are registered and compared to determine the amount of agreement. Such comparisons can be made on a polygon, grid cell, or point basis. These comparisons result in a matrix showing the quantity of omission and commission errors. All methods described to assess accuracy can be applied to either type.

Meyer et al. (1975) used non-site specific accuracy assessment to evaluate a classification of Landsat imagery in Southeastern Montana. Total areas were calculated for each class type. Meyer found that the estimate of the relative proportion of each cover type compared favorably with the ground truth that is, actual area of each land cover category). However, he also noticed that omission and commission errors were obvious and that the overall positional accuracy of the cover types within the areas studied was poor.

In practice, non-site specific accuracy assessments are of limited value since the natural resource manager is usually interested in the location, as well as the area of a certain land cover category. Site specific accuracy, on the other hand, presents a more meaningful representation of the accuracy of the classification. The analyst can see which categories are easily identifiable and which are being confused. Once the error matrix has been generated, a very simple procedure can be used to determine the overall accuracy. As all values on the major diagonal represent pixels correctly classified, the addition of those values divided by the total number of pixels classified will give the overall accuracy of that error matrix. This is the most common use of the error matrix in accuracy assessment (Congalton et al., 1981).

Recently, techniques using regression analysis, analysis of variance, and discrete multivariate analysis have been developed to assess classification accuracy. Each method has certain assumptions that must be met before the technique can be used (Snedecor and Cochran, 1976; Rosenfield, 1980).

Research has also been done to determine effective sample size for accuracy assessment. Various researchers have their own ideas about sample size determination and these have certain merits and demerits. For further details see Hord and Brooner (1976), Genderen et al. (1977), Genderen et al. (1977), Rohde (1978), Hay (1979), Ginevan (1979), Todd et al. (1980).

Accuracy levels achieved in classification of land cover from Landsat MSS data tend to vary considerably due to differences in the nature of land cover, the conditions from region to region, and the classification technique employed. A

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region characterised by large homogeneous areas of land cover will be relatively simple to classify. On the other hand, areas of varied vegetation and topography have complex spectral signatures, therefore making classification more difficult. To conclude, it must be mentioned that estimates of classification accuracy reported in the literature may not be easily compared because of the use of different approaches.

2.5 REMOTE SENSING AS AN INPUT TO GEOGRAPHIC INFORMATION SYSTEMS

Land management decisions rely on accurate information about land cover and its changes over time. From the preceding discussion, it is obvious that Landsat data can provide useful information about various resources, although in most cases management decisions cannot be made on the basis of satellite data alone. Additional ancillary data such as land ownership, soil types, administrative boundaries, environmental and topographic data are also required. The above data attributes form the main components of a Geographic Information System (GIS) using remotely sensed data. Such a type of GIS, especially one using image data as an input, provides very effective techniques for integrating, analysing and displaying data sets of different format, particularly over a large geographical area.

The development of a GIS is mainly attributable to the recognition by planners and resource managers that effective information on resources needs to be timely and efficient. In many instances, the information needs cannot be satisfactorily met by conventional methods. This need would particularly apply to resource related decisions which have financial constraints and may be subject to increasing public and political scrutiny. Moreover, this can also be associated with the rapidly increasing technical capabilities in the field of data processing and remote sensing.

Against this background, a GIS can be defined as an information system which integrates a set of computer programs which handle a variety of geographical data. A GIS enables the user to acquire, encode, store, edit, update, retrieve, analyze, manipulate and display data in both graphic and statistical modes, but with reference to a common geographic base.

Although GIS does not always include Landsat or either remotely sensed data, there are distinct advantages in their inclusion. Firstly, classified Landsat data are usually well matched with other ancillary variables, so that the quality of the information improves. A GIS can very efficiently combine Landsat data with other variables and show them in a variety of geographical outputs and tables. For example, a GIS applied to forest inventories could depict in tabular and graphic form, the distribution of various forest types, their topographic and climatic attributes, underlying soil type, and administrative boundaries for a given region. Such detailed information can effectively be used to improve resource related management decisions.

Secondly, with Landsat data it is possible not only to update baseline information but also to forecast trends due to the retrospective and repetitive nature of the data.

Since remote sensing and automated computer based GIS are relatively new technological developments, it is essential to develop their combined use systematically by taking into consideration resource related management needs and the varied requirements of end users. This is an important requirement for the effective implementation of a truly integrated GIS and is discussed in greater detail in Chapter 3.

Various researchers (Shelton and Hardy, 1974; Shelton and Estes, 1979; Strome et al., 1980; Cihlar et al., 1983; Dangermond, 1983; Bartolucci, et al., 1983; Wilson and Thomson, 1982; and Smith and Hendrix, 1985) have discussed various technical and technological issues related to the planning, design and operation of remotely sensed data based GIS. Integrating their discussions, it seems that the following important issues need special consideration for setting up a GIS:

1. The data needs of various participating organizations should be identified to determine the degree of commonality of data sources which either do or could exist. Categorization and evaluation of their existing data bases and current methods of analysis need to be identified. Moreover, specifications for the new data base should be considered including the georeferencing system taking into consideration the purpose and scope of the present and future information needs.

2. Evaluation of technical alternatives should be performed to permit the extraction of accurate resource information for inventory and data base systems. Cost effective analysis systems should be pursued and applied taking into consideration various

project objectives. Moreover, the procedure for extracting the resource information with the required accuracy must also be defined.

3. Personnel responsible for managing the resource must have the knowledge and skills necessary to use the remotely sensed data effectively or must have ready access to these skills. These include the ability to analyze the data, and familiarity with the capabilities and limitations of the method of analysis.

4. Systematic methods should be outlined for acquiring, encoding, editing, retrieving and storing large quantities of data. Appropriate hardware, software and trained personnel should be available for extrapolating and extracting useful information from the stored data base.

5. Hierarchical classification schemes, data requirements and various classification techniques applied at various stages of the GIS, need to be clearly specified along with their cost and time framework.

6. Digitizing is an important segment of a GIS, since the data are referenced to their exact geographic location and extent. Hardware requirements and the magnitude of computer programming required need to be carefully evaluated.

7. Finally, manipulative software needs to be given special consideration for producing useful information either in map, image or tabular form depending on the convenience of the ultimate users.

Shelton and Hardy (1974) and Shelton and Estes (1979) discussed basic concepts and limitations of the technology for resource managers. They also discussed and categorized issues and techniques related to the extraction and interpretation of information from remotely sensed images as applied to GIS.

To meet the operational resource management information needs of the future, Strome et al. (1980) argued the need for devising compatible and interconnectible GIS, taking into consideration the requirements, capabilities and organizational situations in each nation or region. Faust et al. (1981) discussed some of the issues involved in the design and operational use of a low cost micro-computer based GIS. They pointed out that, to fulfill various users requirements, it is essential to provide application source code for the basic software packages as well as documentation on its theory and use. Moreover, the scale of implementation of such a micro-computer GIS should be twofold, that is, as a stand alone system to be used on an interactive basis, as well as an intelligent terminal to a large computer for data transfer and selection processing. Finally, they considered it important to train field personnel in their working environment.

These researchers discussed in detail the technical issues leading to the successful implementation of remotely sensed data based GIS. The underlying idea was to devise a system that would transfer the best possible information to the decision makers in a form that would be readily accessible and understandable. Many researchers (Shelton and Tilmann 1978; Campbell et al., 1980;

Ader and Johnston 1982; Bussom et al., 1981; Johnston, 1982; Cisse et al., 1984; Maniere et al., 1984; Mendoza et al., 1984; and Teng, 1984) have demonstrated operational procedures for cataloging environmental resources. Information presented as computer graphics output, as well as in a tabular form, help to improve management decisions.

Recent developments in remote sensing and computerized based GIS have application in nearly every field of environmental science. However, the most frequently reported applications of GIS is in the field of water resources, land use and forest inventory. These are reviewed in the following paragraphs.

Accurate information on the water status of a region is an important element in a development plan. Moreover, a land policy cannot be effectively devised without detailed information such as the quality, spatial distribution, total content and potential use of water. In watershed management studies, researchers such as Eidenshink and Wehde (1981), Ragan and Fellows (1982) and Smith and Blackwell (1980) integrated a host of data sources into their GIS. Input data consisted of classification obtained from aerial photographs and Landsat images, terrain and soil type information, watershed boundaries and management boundaries. They reported that such an approach helped in assessing various forms of watershed developments as well as the impact of land use changes. Moreover, the technique also provided very useful information on the physical geography of various political and natural regions in the study area. Thus quantitative information on slope, land cover, soil suitability etc. was simultaneously retrieved and incorporated in the decision making process.

Hall (1981), Frank (1981) and Loveland and Johnson (1983) developed systems to help in water planning and policy decisions. Their data sources included land cover, digital terrain information, soil types, historical and existing water supply, existing water rights and land use plans. They reported that the resultant detailed information enabled them to perform statistical comparisons, monitor trends and update baseline information. The system proved timely and efficient since it was possible to specify those areas which needed immediate attention. Similarly, in Illinois, Frank (1982) established a data storage and retrieval system to inventory the physical, chemical and biological characteristics of streams. He pointed out that information derived from remotely sensed data, such as bankside and riparian vegetation, can provide an important link in the development of such data base systems.

Appropriate long and short term plans play a critical role in better and more effective management of land use/cover resources. Lack of timely and relevant data often forces the authorities to implement planning decisions based on inadequate and superficial information which results in inefficient use of valuable resources.

Roller (1984) described the process of integrating Landsat data with ancillary data in resource inventories. He discussed the most efficient integration procedures and demonstrated a practical application by providing various examples (such as a soil-vegetation survey, a winter cereal crop inventory and a lake survey). Other researchers (Enslin et al., 1977; Stow, and Estes, 1979; Middleton, et al., 1982; and Maggio et al., 1983) reported similar experiences in extracting and merging remote sensing with various land cover inventory data. In Michigan, Enslin et al. (1977) developed a methodology to provide grid based land cover data that was responsive to the specific needs of regional planning agencies. Essentially, it used a cost effective combination of data capture techniques. Land cover classes obtained by computer-aided analysis of Landsat data was blended with some land cover data manually interpreted from aerial photographs and other maps. Stow and Estes (1979) examined the potential of Landsat and National Cartographic Information Centre (NCIC) digital terrain data as an input to a county level information system. They analyzed the accuracy required to incorporate these data into a conceptual geobase information system. By comparing the Landsat classified data with low altitude aerial photographs, they concluded that Landsat derived land cover classification data are a marginally accurate data source for county level resource management requirements. However, the accuracy of NCIC data appears to be unsuitable for GIS applications due to its failure to accurately represent elevation.

In a similar study, Middleton et al. (1982) compared and evaluated the overall accuracy of land cover derived from Landsat data and land cover data provided by the Maryland Automated Geographic Information System. The accuracy of the survey improved with the use of Landsat data. Discrepancies in the results were found to be due to differences in interpretative methodologies, and not due to deficiencies in either data source. Shelton and Tilmann (1978) reported their experiences in Central

America where remote sensing and GIS technology were used in land use planning. They reported that seven project elements encompass both the land inventory and the data system associated with it and are basic to the design of any GIS. These elements include classification, data acquisition, geographic referencing and data input, data storage, retrieval and analysis, and user applications.

The concept of a GIS is well suited to forest management. As Gregory et al. (1981) pointed out, the size, complexity and dynamics of forest operations necessitates the need for a complementary system which blends land cover information, gathered through remote sensing techniques, with an interactive, graphics oriented, computerised data base containing ancillary information. The data base should be capable of updating forest cover information and producing graphic overlays of digitized ancillary data, thus assisting the forest managers in assessing and devising the best planning strategy.

Tomlinson and Boyle (1981) examined nine computer based systems for the Saskatchewan Department of Tourism and Natural Resources, Canada, which was considering the acquisition of a system to handle its forest resource data. Criteria that were being considered for the purchase were the technical capability, ease of use and ability to meet the input data volume, throughput requirements, cost effectiveness and reliability. The comprehensive report that was produced allowed the potential users to assess the degree to which their needs for individual spatial data handling functions were met by the current technology. It also described the capabilities that are difficult to provide and the nature of the problems. The most important problems identified fell into two categories namely, problems related to the basic system capabilities and map data handling capabilities. System problems may centre around digitization, edge matching, polygonization, labelling, plotting, data storage, management and data updating and report generation. The later may include data manipulation, data generation in different graphic form and data extraction and interpretation.

Similarly, Hegyi and Quenet (1983) and Myers and Kolenik (1984) briefly overviewed two georeferenced information systems for inventory of forest resources at different legal and administrative boundaries levels. The system is meant to provide statistics such as forest types, logging, insect attack, forest fire and monitoring of changes in the data base. They also identified several requirements which need to be examined for evaluating candidate systems for forest inventories. They concluded that such systems increase the efficiency in the production of forest cover maps, update changes without redrafting the entire map, generate resultant polygons with areas, and create grid oriented data files for data management and retrieval on a large mainframe computer.

In Colorado, Garratt et al. (1982) demonstrated the feasibility of merging Landsat digital imagery with terrain, existing forest inventory information and field data, so as to create a cellular data base. his data base would enable mapping of forest resources, and detection and updating changes in forest areas and would provide a base from which to initiate the subsequent inventories of the forest resource. In central California, Strahler et al. (1983) reported their experience in the timber inventory of the Eldorado National Forest. A raster based GIS was used to stratify large areas of land and to allocate, aggregate and process point sample data. Similarly, in western Montana, Martin (1985) outlined an approach for mapping photointerpreted forest maps and discussed the practical application of a computerized GIS in timber stand management.

Some researchers have also investigated the utility of these data bases for monitoring and managing forest fires. Forest fire protection policies are one of the most important segments of forest management programs. Effective fire protection plans need detailed information about the nature of vegetation, topography and climate so that timely actions con be taken to conserve the resource.

Most of these studies used Landsat based vegetation/fuel categories and merged them with topographic and weather data and records on previous fires. Shasby et al. (1981) and Sader et al. (1982) mapped forest fuel classes using Landsat and topographic data. These fuel classes served as an input to forest fire models for fire danger rating and for devising forest fire related management plans. Maw and Brass (1982) developed a data base in California to tackle various forest management problems. They integrated and registered various data sets to a Universal Transverse Mercator (UTM) grid base. These included a Landsat classification, soil types, digital terrain data, land ownership, jurisdictional boundaries, fire events and generalized land use. The system was used for fire management and reforestation planning. Henderson and Vindigni (1981) highlighted the information needed for fire service planning. This includes fire station location, fire equipment depending on the variability of area and pre-fire planning operations. They concluded that techniques based on remote sensing data can effectively contribute to the development of comprehensive fire fighting plans.

2.5.1 SUMMARY

It may be concluded that a GIS, especially one using image data as an input, is an effective technique for integrating, analyzing and displaying data sets of different format. The development of the GIS is mainly attributable to the lack of readily available data from conventional methods. Moreover, the emergence of GIS can also be associated with the rapidly increasing technical capabilities in the field of data processing and remote sensing.

Data information required for resource planning and management includes topography, soil types and climate. In the reported literature, these data have been merged with remotely sensed data to form the GIS. Much of the information in a GIS does not significantly change from year to year. As a result the cost of maintaining the system is minimal after its initial building. Land use and cover change from time to time. But this type of information can be updated quite economically by integrating digitally processed Landsat MSS or either remotely sensed data.

The above literature review could provide useful information to resource managers who have been concerned with the spatial distribution, identification and inventory of resources over a large geographical area. Improved spatial and spectral resolution provided by the Landsat Thematic Mapper and SPOT imagery will undoubtedly increase the existing classification performance and effectiveness of integrating remotely sensed data with other GIS attributes. I conclude this Chapter by quoting Kalensky and Wightman (1976):

> "Remote sensing from resource satellites provides mankind for the first time with a potential capability for worldwide resource mapping and environmental monitoring in near real time. The importance of such readily available and objective information about the distribution, quality and exploitation of natural resources can hardly be ignored".

CHAPTER 3

REMOTELY SENSED DATA AS AN INPUT TO A FOREST INFORMATION SYSTEM

The concept of a Geographic Information System (GIS) was discussed in the previous Chapter. Various issues related to the development of a GIS were also discussed along with their applications in various fields. This Chapter will concentrate on various types and structures of GIS. The emphasis will not be on the development of a particular structure but to demonstrate the technique of merging image data with other data types. The conceptual framework for a broad GIS is developed and a major part of that framework is applied to forest resources management in Tasmania. Specifically, the major objectives of this Chapter are:

1. To demonstrate the utility of merging raster based remotel sensed data with polygonal data and;
2. To analyze how the output from image processing can be integrated into a polygonal GIS with spatial units which are aggregates of the cells (pixels).

3.1 INFORMATION SYSTEMS

The term "information system" is very broad and encompasses all systems designed to store, manipulate and present diversified resource information. The purpose of any information system is to facilitate the creation and use of information. There are three main components of a spatially based information system which uses remote sensing. They consist of an input system, data base management, and output and display.

The input system includes the collection of data from multiple sources (such as aerial photographs, satellite imagery, maps and statistical data) and the creation of a data base by transforming the collected data into a consistent format suitable for future use. Data base management, generally requires complex mathematical processing and a whole range of statistical analyses. The data output and display consists of printed statistical reports and tabulations as well as graphs, maps and images. The common purpose with which these three components interact is to supply the information in a format required by resource users in an effective manner.

Figure 3.1 shows the main components and functions of an idealized information system capable of integrating and using remotely sensed data for resource planning and management. Miller (1982) pointed out that an integrated information system could be formulated as a collection of independent modules for each of these three components. These components may operate on a single computer, on different computer systems in a single organization, or as independent systems in different organizations with the computer routines necessary to establish proper interfaces.

A number of different terms conveying the same meaning are sometimes associated with geographical information systems. These terms mainly include, environment or environmental, geographical, geographic-based and geobased information system. In this thesis, because Landsat multispectral scanner data, digital terrain data and administrative boundaries data are being integrated in the

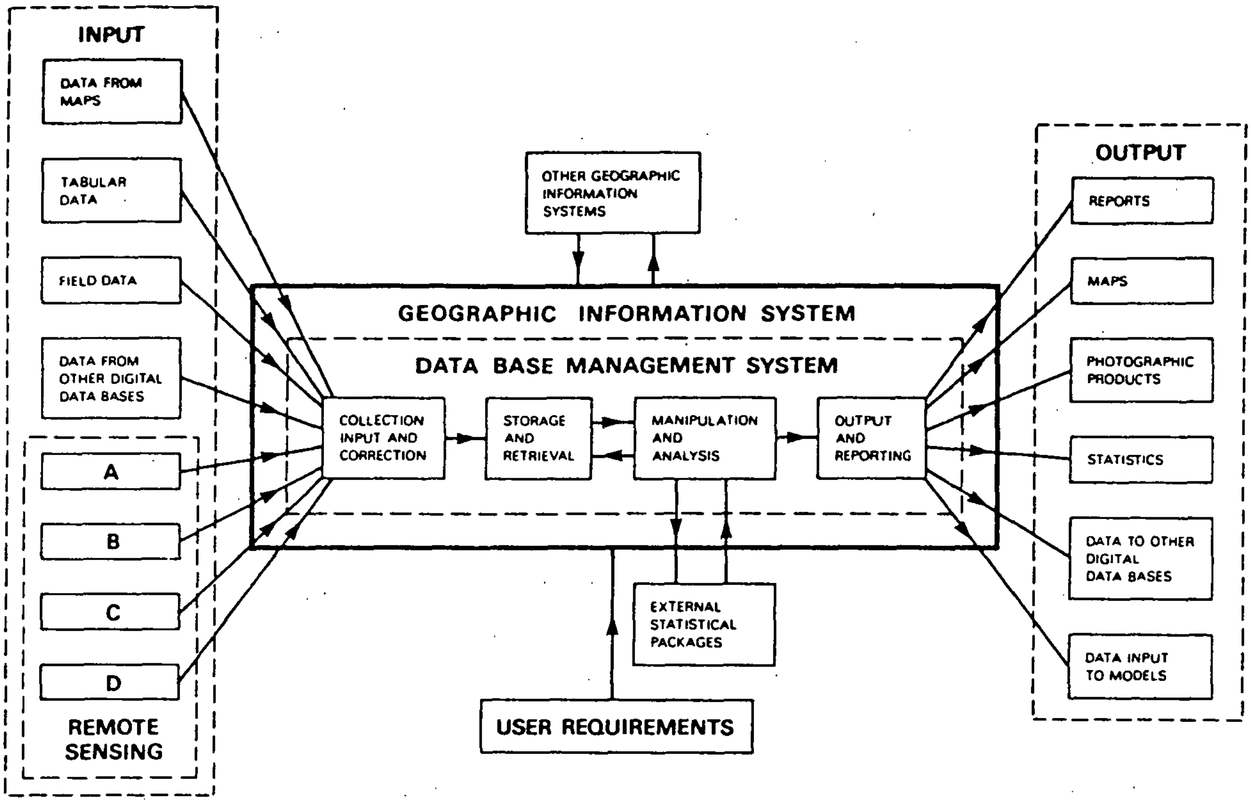

Figure 3.1 : Remotely sensed data based ideal Geographic Information System
(Source : International Journal of Remote Sensing 7(6), 1986).

context of a Geographic Information System, therefore, the term GIS will be used for such an information system.

The most significant difference between a GIS and other information systems is in the spatial or geographic nature of the data. In a GIS the data base consists of observations on spatially distributed features, activities or events which are definable in space as points or areas. Therefore, a GIS would be taken to mean a data base in which spatial location is a primary attribute.

The most desired features of a GIS, especially when it is to be used for generating forest resource information are those which would have the ability to

1. incorporate a variety of data structure
2. have the ability to respond to a number of management activities using the above mentioned data
3. be easy to implement
4. be cost and time effective in generating information compared to alternative systems, and
5. be credible to the planners and ultimate users.

3.2 TYPES AND STRUCTURE OF GIS

The geographic data structure incorporated into a system plays a dominant role in classifying a GIS. The data structure refers to the organization of the data which is stored in the computer. This in turn significantly influences the way the data are collected, their volume, the types of analyses and the product that can be produced.

Data used in a geographic information system can be classified into three different types: points, lines and areas. Points are generally used to identify locations of features which have no areal extent. The data structure in this case is generally, a list of (X,Y) coordinates with an attribute or attributes associated with the points. Lines are used for linear data such as road and stream networks assuming that these variables have no areal extent. Lines are described by strings of (X,Y) coordinates with the begining and ending points of the line segments being called nodes. However, the majority of data is represented by areas such as land use types, forest and vegetation types and various administrative and cadastral units.

The types and structures of GIS's reported in the literature are vast but three types which are partially relevant to the theme of this thesis are distinguished as follows:

3.2.1 DATA BASE SYSTEMS

As defined by Pazner et al. (1983) a data base is an integrated and shared repository of stored data, and data base systems are computer systems that manage databases so that they can be interrogated. In other words a database system is simply a computer-based record filing system. A data base management system (DBMS) refers specifically to the software that handles access to the data base. There are three essential components in a database system:

- an organized collection of data
- modules for manipulating, retrieving and analyzing data to produce usable information, and

. an interactive data manipulation language for querying and altering the data using the above modules.

In these systems spatial data are held against some basic spatial units such as forest blocks. The data attributes are then associated with these spatial units. The information output is generated by searching, sorting and tabulating these units and mostly includes computer generated colour-coded maps and charts, printed statistical summaries and digital output files. In this thesis, an example of GIS summary statistics would be a table of land cover statistics by forest block or district. The output may also include derived data sets which can be used in a recursive manner to add new attributes to the data base or to further refine the analysis.

There are some severe obstacles in the implementation of DBMS concepts for spatial data. As Tomlinson (1979) pointed out, the sheer volume of data, especially areal data sets frequently encountered in land use planning, exceeds the capabilities of any readily available DBMS. Also, until specific requirements are identified, it is difficult to determine what spatial entities are important and how they are best represented in a digital file, what specific relationships between various entities are important, and what operations must be performed on the data.

It is well known that, although such systems are efficient for data storage, the spatial location of the data is not easily accessed. For example, queries such as "all records which are near roads" become difficult to express in the DBMS unless other attributes like "distance to the road" are added. This obviously leads to increased data storage requirements in the system.

3.2.2 POLYGONAL SYSTEMS

These systems are better representations of the geographic data, because the actual location and spatial form of the data is stored with the attributes. In polygonal systems the spatial structure, especially the hierarchial structure induced by inclusion of units in larger units, is more developed. The boundaries of the basic unit are digitized and entered into the system regardless of the unit shape, and these may themselves carry information on neighbours and adjacency.

The most common grid structure used in a data base system is that of a two dimensional matrix (or spread sheet), whilst in polygonal systems more complex structures need to be constructed. As mentioned earlier since lines are represented by two endpoint nodes, a polygon system can handle point and line data effectively. In polygon encoding (one logical record per polygon) of the data, it is necessary that every line be digitized twice: once for the polygon on the left of the line and once for the polygon on the right. This can lead to the generation of different X and Y coordinates for the same point. Therefore, procedures and programs need to be incorporated into the system to reconcile coordinates for a common line across separately digitized polygons to remove slivers and gaps. (Slivers and gaps refer to the lines or boundaries produced by double digitizing). For further discussion on polygonal structures see Peucker and

Chrisman (1975) and Dangermond (1978).

3.2.3 IMAGE OR CELL BASED SYSTEMS

The framework in which many spatial questions are most easily solved is the image or grid cell system. These systems are based on a raster data format. Systems comprising this type of data use a very fine raster data grid as their basic unit of data storage (Zobrist, 1976). Similar to a grid system, the structure of the raster system is a two dimensional matrix. Such systems capitalize on image raster scanning technology, where data are referenced to a small spatial unit (usually called "pixels" or picture elements).

These systems, because of the identical nature of their spatial elements (in terms of shape and size) are preferred over others where there is a great complexity of patterns. In general, software development for almost any application is easier for a cellular based approach than for the alternative systems. Although, these systems demand higher storage, they enable image processing, spatial analysis and neighbourhood analysis. Moreover, information queries based on spatial relationships can be accessed most easily using cellular based systems.

However, data based and polygonal systems are storage efficient. They are also more efficient for DBMS searches, sorting and sieving on the data held against the basic spatial units which may correspond to many grid cells in an image-based system. Nevertheless, when data are aggregated into a spatial unit, the validity of associating that data to a smaller specific grid cell within the unit can be questionable if operations are made on the cell data which assume a precise relationship between data and location.

For these reasons, the current state of GIS tends to support systems which are operated in the form which is most suitable to the purpose of processing and in which both cell and polygonal data could be incorporated because of their unique characteristics (Table 3.1).

In this thesis, therefore, the emphasis is not on the particular structure of a Geographic Information System but rather to develop a GIS which demonstrates the techniques of merging different data types and, in particular, image data. A conceptual GIS is formulated and empirically demonstrated for forest resources management in Tasmania.

3.3 FORESTRY INFORMATION SYSTEM

A need exist for information that will enable the forest manager to develop land use and land management policies, regulate and monitor the existing use of land, and implement these policies through resource management activities. The increasing pressure for environmental legislation has further stimulated the need for generating speedy and accurate resource information. Many researchers have discussed the potential benefits of remotely sensed data based information systems. In most cases these systems are unique since they consist of differing data types which are tuned to specific geographic locations.

Table 3.1

Characteristics of map based polygonal and remotely sensed cellular data

Remotely sensed Cellular data	Map based Polygonal data
- Raster format	- Vector format
- Synoptic nature	- Sampled
- Routinely updated	- Rarely updated
- Low resolution	- High resolution
- High data storage requirements	- Variable storage requirements
- Two dimensional representation of areas of interest	- Two dimensional representation of areas of interest

An information system developed for Tasmania would need to analyze map and create tabular outputs of forest resources. Typically, it could include land cover and relief information for logging areas, information on ecological zones for formulating fire strategies etc. Cadastral boundaries would form an important component of the system since they would ease management policies for targeted areas.

3.3.1 DIGITAL DATA BASE DEVELOPMENT

Land cover and topographic data are two of the major information inputs required in a forest resources management system. These data describe both the cover and relative variations of the surface terrain which are essential in the management decision process. In addition, administrative boundary data enable decisions to be applied at various levels of aggregation and at specific geographical locations. Three different data layers which were integrated in the development of this GIS are given in Table 3.2 along with their source.

3.3.2 DIGITAL DATA PROCESSING

After data collection, the need arises to convert data into machine readable form for input into the system. Two types of processing were performed on each of the data layers listed in Table 3.2. It consisted of, firstly cataloging the data into appropriate groups, and secondly spatially transforming the three data layers, which had different projections and spatial resolutions into a common spatially congruent system of latitude and longitude coordinates (see Figure 3.2).

Table 3.2

Data layers selected for analysis

Data type used	Source
Land cover types	Landsat MSS data
Elevation, slope, aspect	Digitized topographic maps
Administrative boundaries	Photo-interpretation type maps

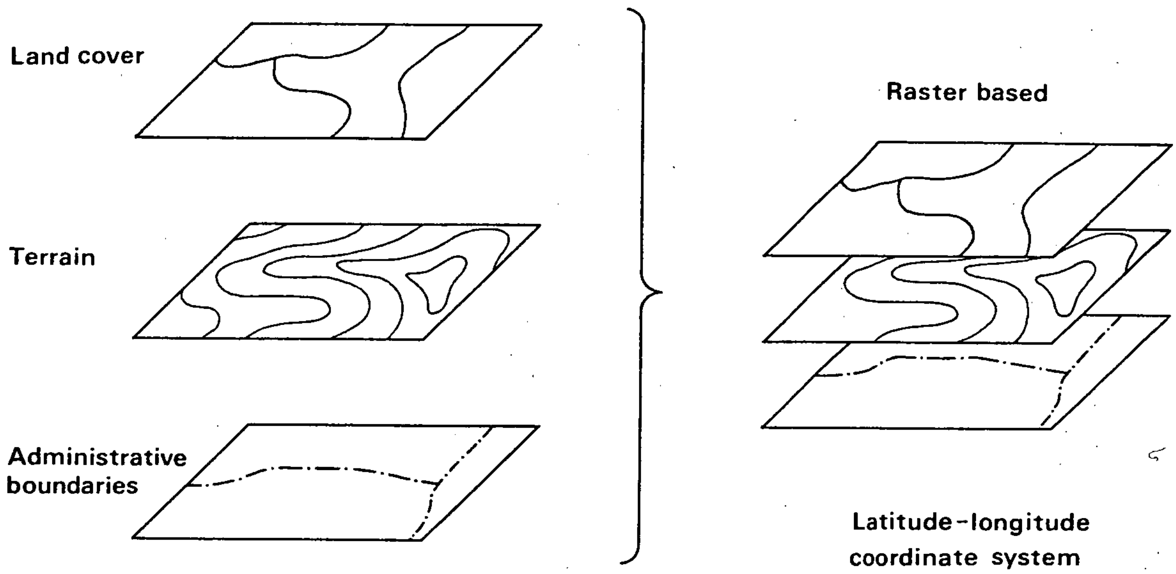

Figure 3.2 : Integration of different data layers.

Various methods for categorizing land cover types based on spectral data alone have been discussed in Chapter 2. However, terrain elevation is an intrinsic factor in determining vegetation type and provides added useful information when treated as part of a GIS. The next section provides information on the elevation data used, and its processing and integration with the other data sets.

3.4 DIGITAL TERRAIN DATA

In the literature, digital terrain data is discussed with reference to digital elevation or digital terrain models which consist of an ordered array of numbers representing the spatial distribution of terrain characteristics. Generally, the spatial distribution is represented by an XY horizontal coordinate system and the terrain characteristic which is recorded is the elevation coordinate Z. An alternative approach is to define position by latitude, L1, and longitude, L2, and the terrain elevation by H.

3.4.1 DATA ACQUISITION

Digital terrain data used in this project were taken from 1: 100 000 topographic map sheets produced by the Mapping Division, Lands Department, Tasmania. In order to transform the map data into a computer readable form, five sheets which covered the entire study area (Figure 3.3) were scan digitized by Tennyson Graphics (Pty, Ltd.) in Melbourne. In this digitizing technique, stable base overlays containing all the contours are placed on a drum which rotates under a fixed light source. Each

Figure 3.3 : A part of 1:100 000 topographic map covering the study area.

time a contour line is detected, the X and Y coordinates are recorded on a magnetic tape. The resulting data was interpolated to a 50 meter grid with each grid cell containing an elevation value. The elevation information contained in the data ranged from sea level to 1350 meters. The digitized data was provided as five files on a 1600 bpi magnetic tape.

3.4.2 DIGITAL TERRAIN DATA PREPROCESSING

Raw digital terrain data are rarely in a form suitable for immediate use. Some preprocessing is generally required to arrange the data in the required format. Therefore, the following preprocessing steps were performed:

3.4.2.1 FORMATTING

The magnetic tape containing the terrain data was in a unique format (block structured form), therefore a special program was written which allowed data to be converted to a single channel binary file in raster scan lines with true height values.

3.4.2.2 VISUAL INSPECTION OF THE DATA

Because the terrain data used were in five different files, another program was written to subset areas of interest from each of the files in a format compatible with the image processing system used (microBRIAN), thus allowing visual inspection. This was accomplished by creating a lookup table and compressing the elevation data range from 0-1350 to 0-255.

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3.4.2.3 GEOMETRIC RECTIFICATION

Data in a GIS context must be rectified so that the grid elements may be accurately referenced to a geographic location. The rectification procedures followed in this study involving the conversion of map to image coordinates and vice versa, have been thoroughly discussed in Chapter 5 and Appendix A3.5. Transformation equations generated in this process were then used to find out the DTM line and pixel and the corresponding line and pixel in the Landsat scene. This later formed the basis of the registration of the different data sets.

3.4.2.4 REGISTRATION BY RESAMPLING

Registration is an integral part of both the rectification or, geometric correction process. It determines the relationship between the distorted remotely sensed imagery and its position on a horizontal plane as defined by the projection of interest to the user. Image based information systems, incorporating a raster grid storage scheme, require considerable data processing to make their data compatible with the chosen projection. This registration is achieved by using resampling techniques to form a common grid. These techniques relate the origional image grid to a uniform grid in the selected projection.

The two most widely used grid systems are Universal Transverse Mercator (UTM) and latitude and longitude coordinates. Each system has its advantages and disadvantages. UTM coordinates are frequently used but distortions of the projection away from the central meridians poses calculation problems across zones.

Latitude and longitude coordinates are potentially the most accurate and the most easily transformed but distance measurements are difficult since spherical trigonometry needs to be used.

In this study, a latitude and longitude coordinate system was used, and the different data layers were registered and resampled to a two second grid using the mMAPPR program of the microBRIAN image processing system. This program uses the nearest neighbour approach to resample a set of images onto a base grid using transformations files which convert between the map coordinate system and the line/ pixels co-ordinates of the image.

3.4.2.5 MOSAICING

Five 1: 100 000 map sheets covered the entire study area (Figure 3.4). It was therefore, necessary to mosaic the data. This was performed by using microBRIAN software. This software, by joining different conforming image files together, builds a large image which is not restricted to 512 pixels width. Any part of this mosaiced image may be subsetted for further analysis.

3.4.2.6 SUBSETTING

The system used in this project allowed files to be between 1 and 512 pixels in width. From the mosaiced image, therefore, four subsets (450 pixels by 1190 lines) covering the entire study area were extracted for further processing.

3.4.2.7 DATA CLEANING AND FILLING

While analyzing the digital terrain data, it was noticed

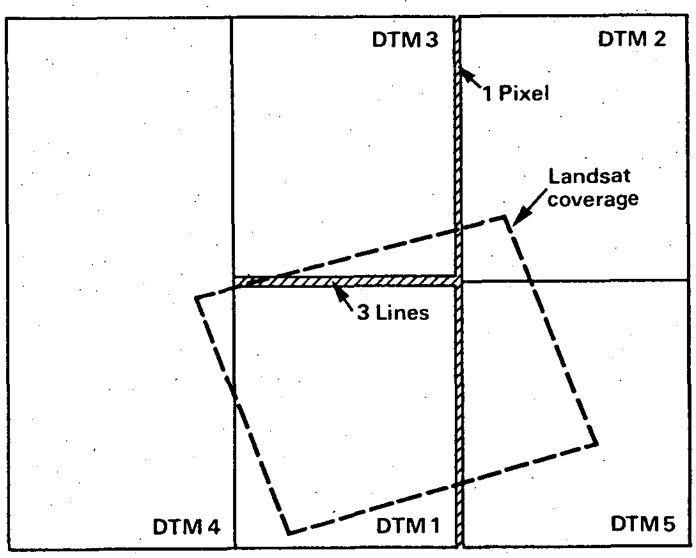

Figure 3.4 : Coverage of Landsat image with respect to 1:100 000 topographic maps. Shaded lines represent data errors

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that on the edges of three map sheets (see Figure 3.4), either some consistent data were missing or some errors in the data were present. To overcome this problem, the erroneous data were spectrally digitized out and the missing pixels and lines on the edges were replaced by the average of the three neighbouring pixels using the mFILLA program in the microBRIAN software system.

3.4.3 TOPOGRAPHIC SLOPE AND ASPECT CALCULATION

A major use of terrain data in the context of a GIS is that they provide the ability to calculate slope and aspect at the individual pixel level and to use this information as an additional registered channel with other data layers. Slope is a critical component for many resource management considerations because it is one of the most important characteristics of land form. Because of their importance in forest resource management decisions, slope and aspect were incorporated in the forest information system developed here.

Slope and aspect can be defined using a plane which is tangent to a given point. In estimating slope it may be observed that many tangent planes could be defined according to the spacing between points. As Stow (1978) pointed out, the selection of point spacing determines the number of tangential planes or slope facets. By calculating slope from a matrix of elevation values, a plane tangent to the centre point based on a neighbourhood of points is found. This plane then becomes the representative of the grid cell.

The tangent plane to an elevation model is defined by the normal to the plane at the point of the surface. Mathematically, the relationship is as follows:

If the elevation at point (x,y) is denoted Z(x,y) and we write

$$p = \frac{\partial z}{\partial x} \qquad q = \frac{\partial z}{\partial y} \tag{3.1}$$

then the normal to the tangent plane at (x,y) with direction cosines (l, m, n) may be computed by the relationships:

$$l = \frac{-p}{\sqrt{1 + p^2 + q^2}} \tag{3.2}$$

$$m = \frac{-q}{\sqrt{1 + p^2 + q^2}} \tag{3.3}$$

$$n = \frac{1}{\sqrt{1 + p^2 + q^2}} \tag{3.4}$$

The slope at (x,y) is the magnitude of the vector (p,q) and the aspect is the direction it makes relative to a fixed direction (clockwise from North)

and

$$\text{slope} = (p^2 + q^2)^{1/2}$$
$$\text{aspect} = \arctan(q/p) \tag{3.5}$$

The slope is often expressed in terms of the slope angle or percent slope which is defined to be:

$$\text{slope angle} = \arctan\{ (p^2 + q^2)^{1/2} \} \tag{3.6}$$

and is an angle between zero and 90° indicating the steepness of the landform at (x,y).

Slope and aspect were calculated in this study using the mINSOL program. This program uses elevation as one channel of an input image to compute smoothed elevation (Figures 3.5 and 3.6), insolation (Figure 3.7), slope (Figures 3.8 and 3.9) and aspect (Figure 3.10) as channels of an output image. The insolation is defined using the slope vector and the direction from (x,y) to the sun position (l_s, m_s, n_s) where:

$$l_s = \frac{-p_s}{\sqrt{1 + p_s^2 + q_s^2}} \qquad (3.7)$$

$$m_s = \frac{-q_s}{\sqrt{1 + p_s^2 + q_s^2}} \qquad (3.8)$$

$$n_s = \frac{1}{\sqrt{1 + p_s^2 + q_s^2}} \qquad (3.9)$$

For further details of the algorithm used in the program see Horn and Bachman, (1978).

For a Lambertian surface, the insolation and the illumination are just the cosine of the angle between the normal to the elevation surface and the sun vector (cos Θ). Treating the direct beam solar radiation as unity, the random load can be described as:

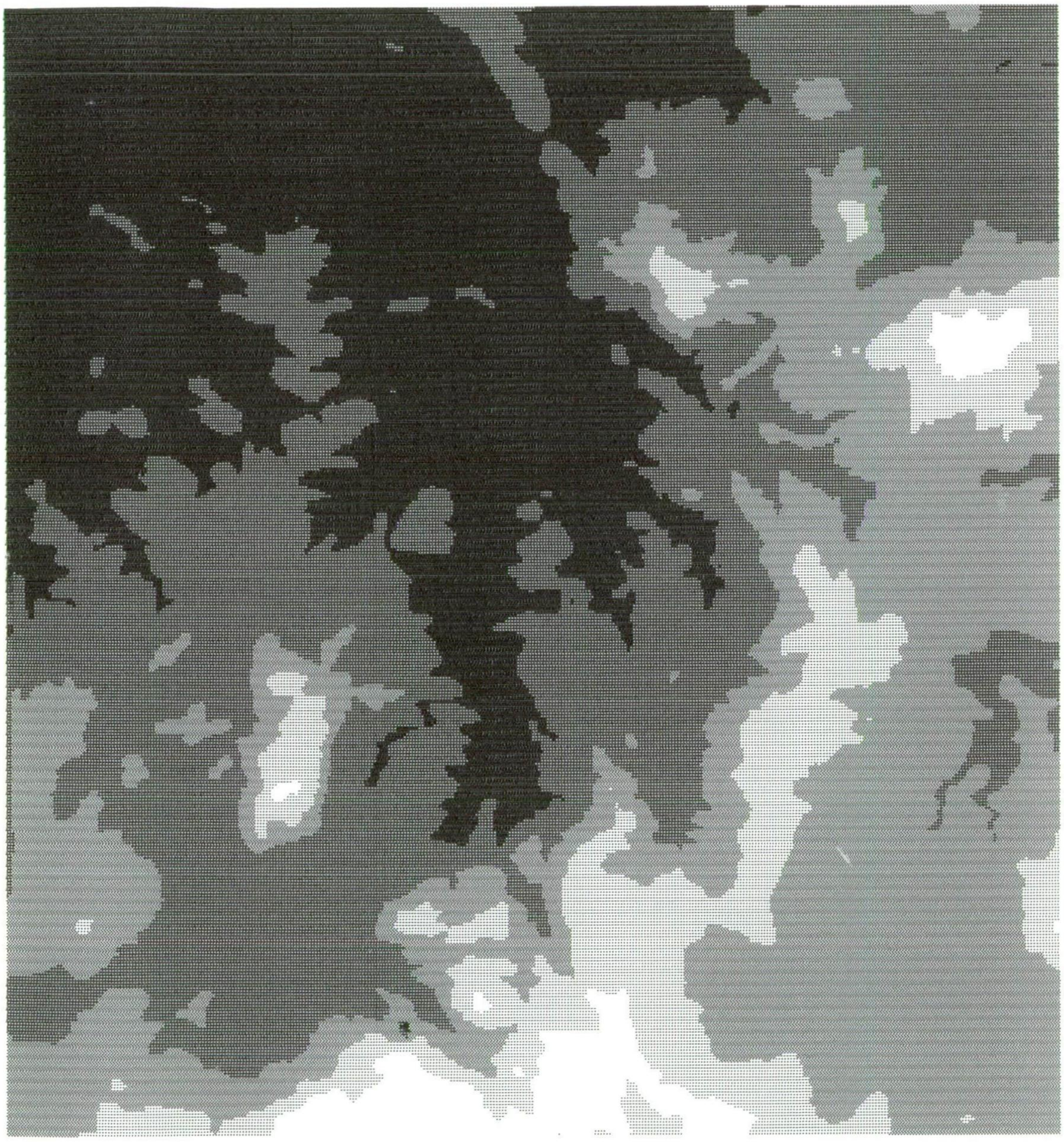

Figure 3.5 : Raw digital terrain data of the representative study area (see Figure 5.2). Lighter tones represent high altitude whilst low relief areas are represented by darker tones.

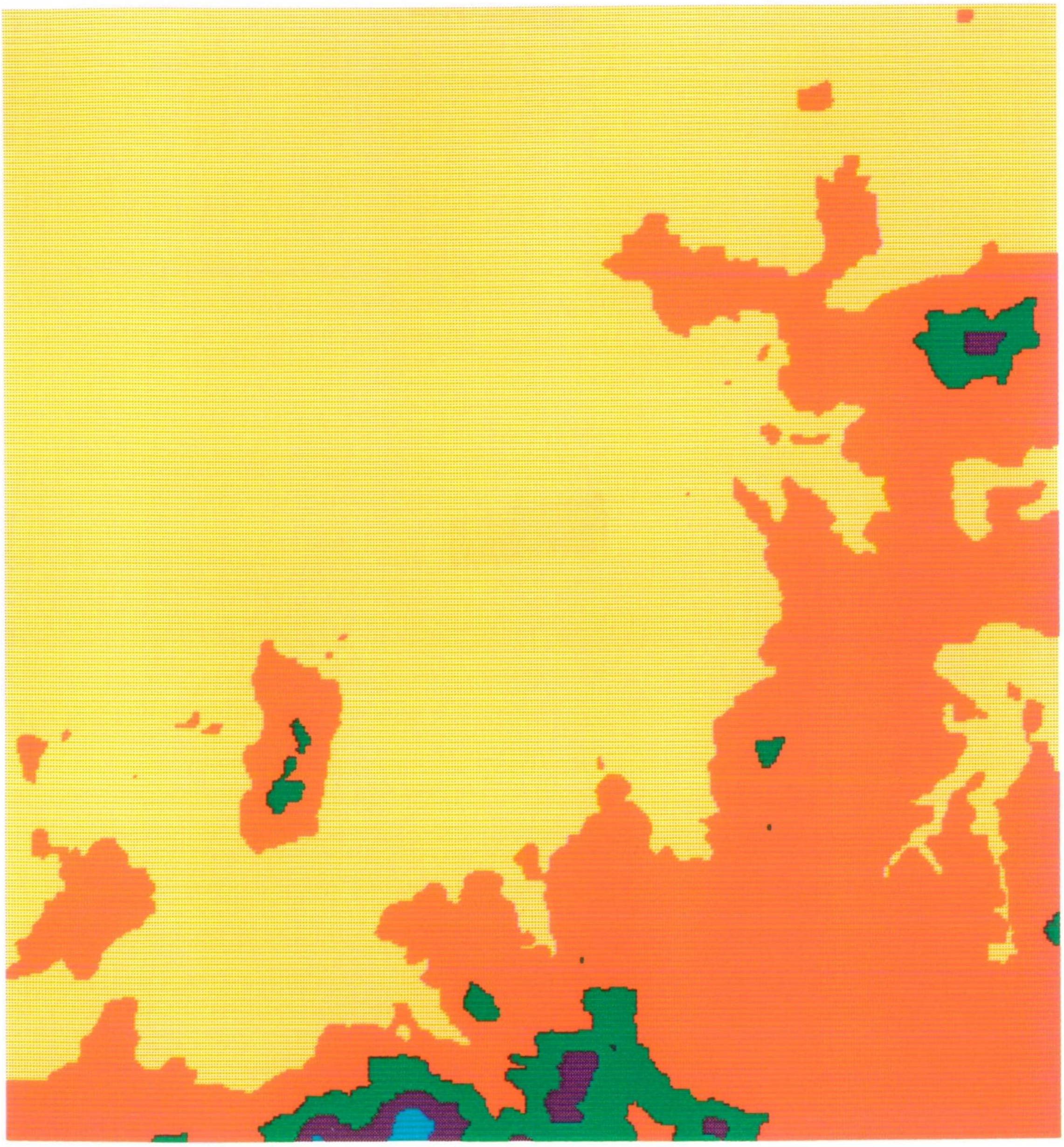

Figure 3.6 : Elevation range (in metres) for the representative study area.

<200	Yellow	600-800	Purple
200-400	Red	800-1000	Blue
400-600	Green		

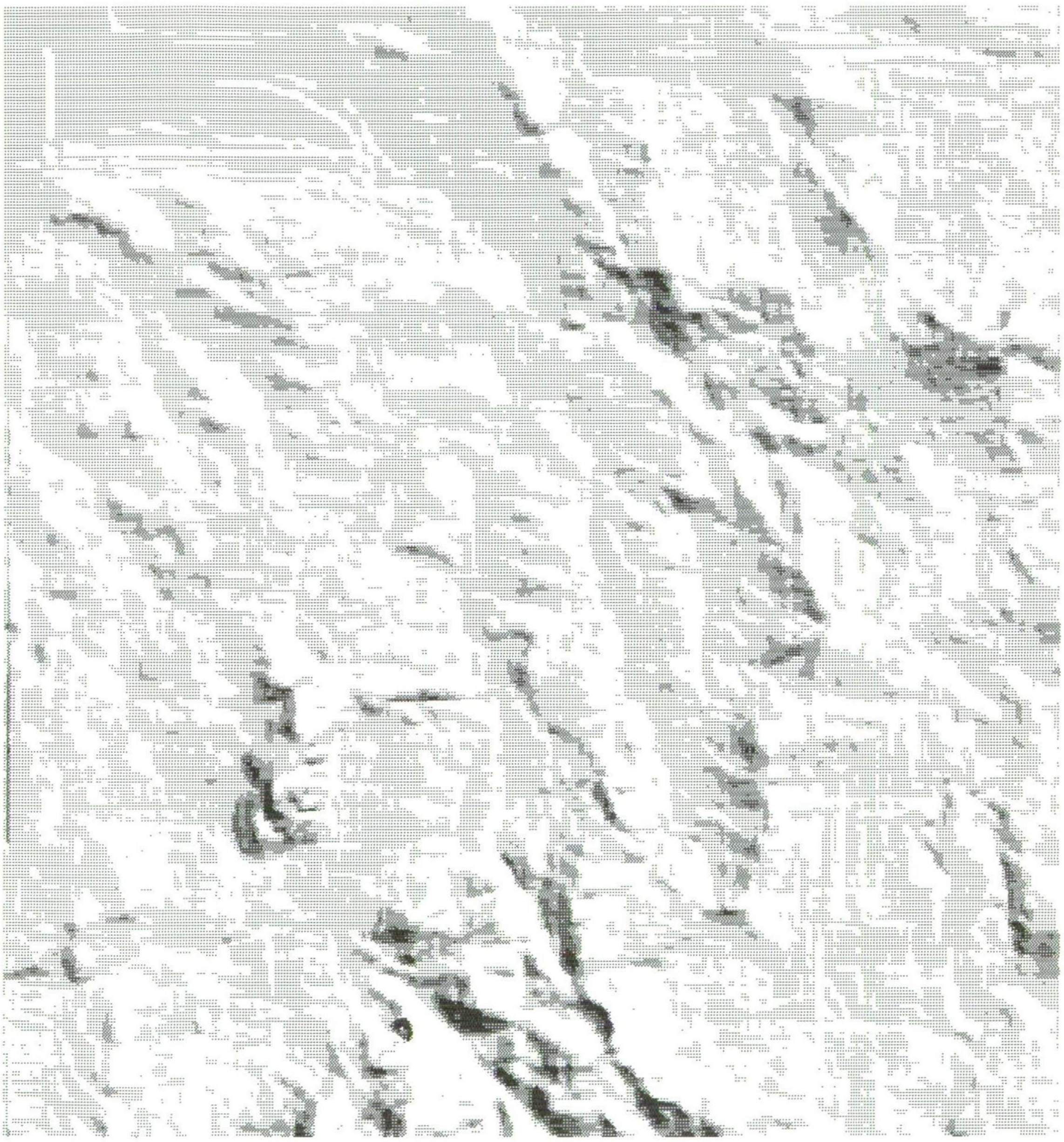

Figure 3.7 : Insolation image for the representative study area. Lighter tones represent high solar loads. Darker tones represent little or no incident direct beam radiation.

Figure 3.8 : Slope image for the representative study area. Lighter tones indicate steep slopes. Darker tones indicate gentle slopes.

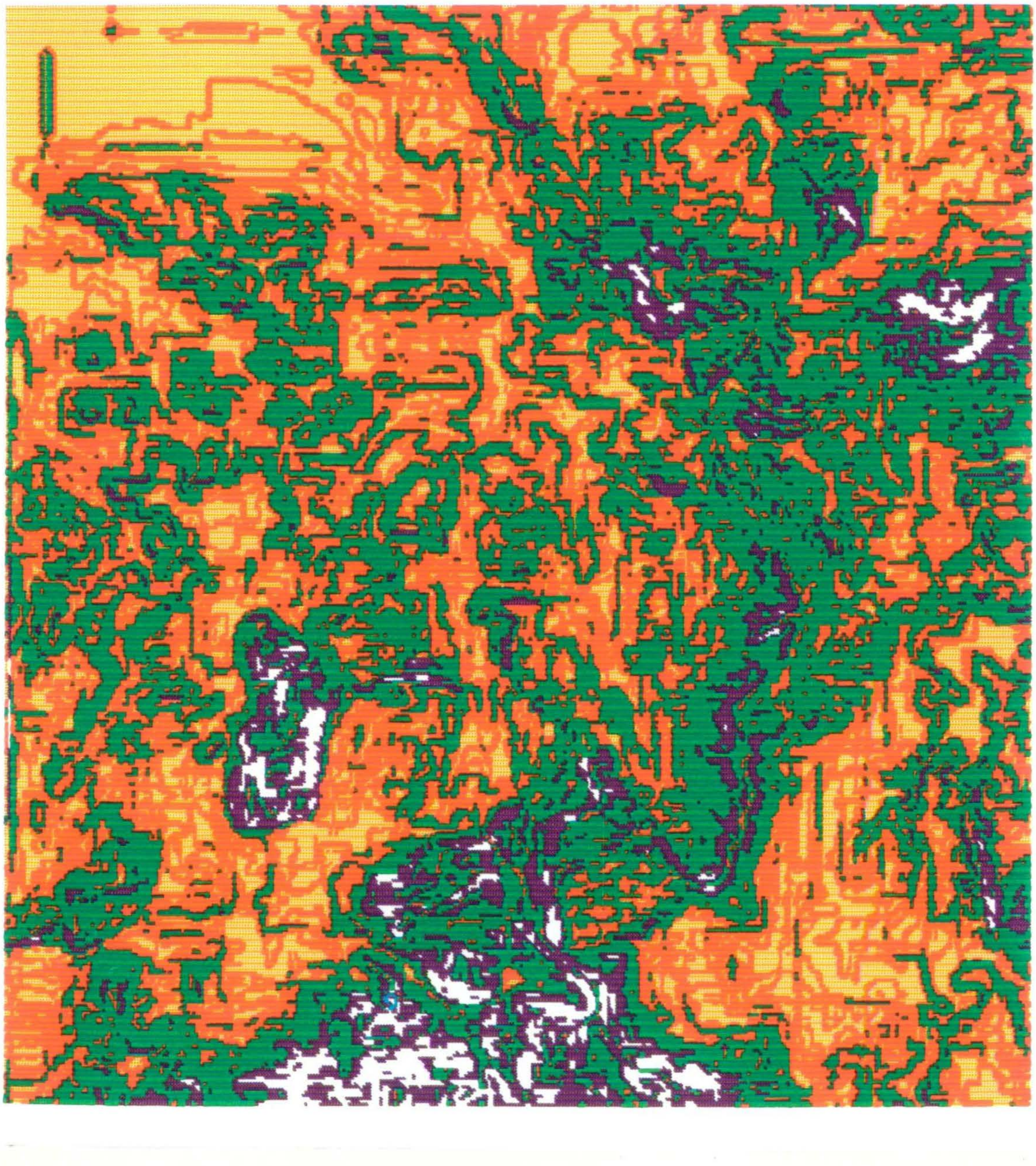

Figure 3.9 : Colour coded slope categories.

<3%	Yellow	32-56	Purple
3-10	Red	>56	White
10-32	Green		

Figure 3.10 : Aspect image of the representative study area.

$$\cos \theta' = l\, l_s + m\, m_s + n\, n_s$$

$$= \frac{p\, p_s + q\, q_s + 1}{\sqrt{1 + p^2 + q^2 \quad 1 + p_s^{\,2} + q_s^{\,2}}} \qquad (3.10)$$

Generally, this model provides the means for estimating useful environmental parameters, such as the site radiation index, for a variety of GIS operations.

3.5 A CONCEPTUAL GEOGRAPHIC INFORMATION SYSTEM FOR FOREST RESOURCES IN TASMANIA

The greater accessibility of remotely sensed image processing systems have enabled many state agencies and private companies to develop their own remotely sensed data based GIS in mini or micro-computer environments. Jupp and Ahmad (1987), highlighted nine components of a modern geographic data system which can be effectively linked in a micro computer system. These may be grouped into three basic sections:

1. the geographic data base
2. the geographic map base and
3. the image data base

Each section consists of a data base and a data collection system which is driven by a management system. In Figure 3.11 these three sections represent activities, well established softwar and their applications. For example, the data base could be managed on software as accessible as the personal computer (PC) based LOTUS 123 or dBASE III. The map base by a gridding and

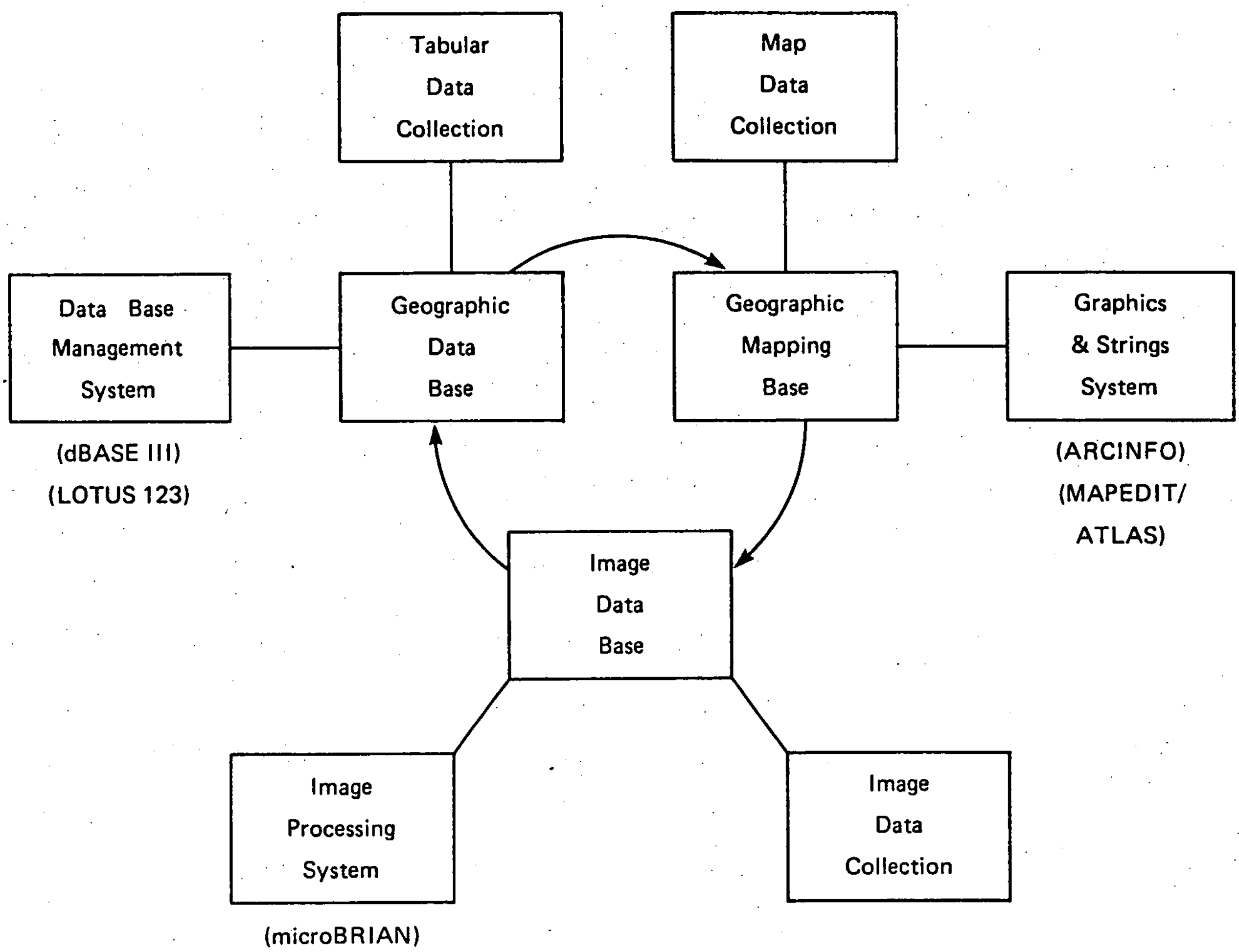

Figure 3.11 : Interactions in remotely sensed data based modern GIS

contouring package together with a polygonal strings package such as PC-ARCINFO and the image data by an PC based image processing system such as the microBRIAN system used for much of this thesis.

In this thesis, a conceptual GIS for forest resources in Tasmania is developed using the microBRIAN image processing system. A conceptual GIS referes to a system which is not completely operational and is basically idealized (Figure 3.1). The information system is limited in that not all data types which are essential for an ideal operational system are analyzed. Only Landsat MSS data, digital terrain data and different forest blocks administrative boundaries data are used and integrated into the system. However, these three data layers exemplify the framework for integrating and analyzing subsequent data layers essential in the formulation of an operational system.

Some components of the forestry information system developed in this thesis are highlighted in Figure 3.12. The system sits together since various data types can move freely between the components. Some of the transactions involved in the working of the proposed system are discussed as follows:

In Tasmania, each forestry district or management zone or forest block can be represented spatially by their boundary strings taken from aerial photo-interpretation type maps or from 1: 100 000 topographic maps. These boundaries can be represented as digital strings using PC based string digitizing systems like MAPEDIT, ARCINFO or AUTOCAD. These strings are usually an attribute in the data base (especially GIS software like ATLAS)

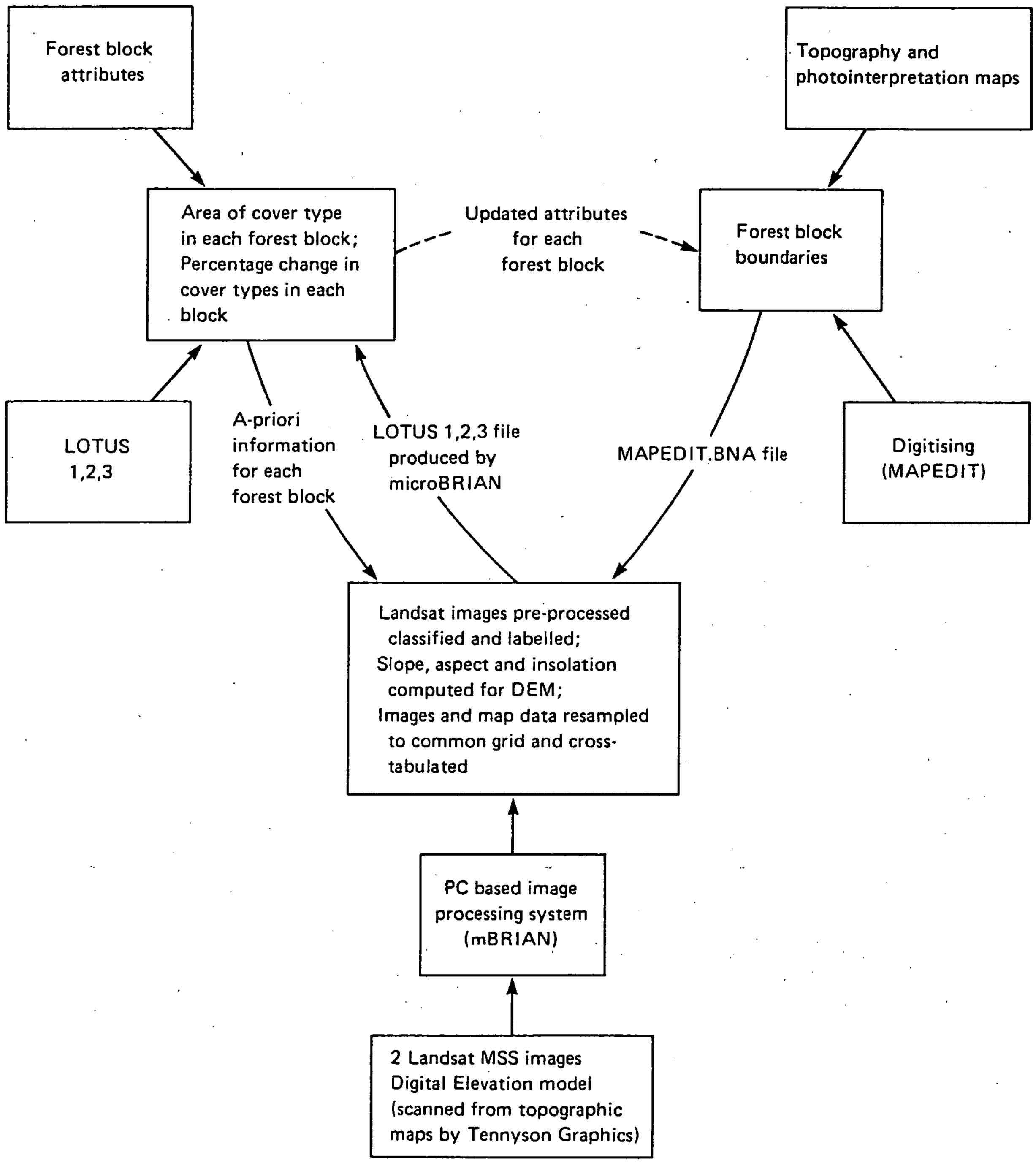

Figure 3.12 : Forestry information system.

and are represented in the mapping base so as to geographically plot data base queries and attributes. These polygonal strings can then be transferred as raster images into the image processing system using raster to vector conversion software routines.

Using the image processing system, tabular summaries may also be generated by interpreting remotely sensed images. This process of generating tabular information such as land cover types is thoroughly discussed in Chapter 5. Similarly, as discussed above, terrain information such as elevation, slope and aspect can also be generated by using image processing systems.

The salient output of the image processing component as highlighted in this thesis is the classified land cover and land cover change information for each pixel and its respective terrain information tabulated for each polygon or administrative unit. The tabular information generated can take the form of a frequency distribution depicting the number of pixels and their terrain characteristics, within each forest block separately or for the complete district.

The new data plane constituting the tables or various spreadsheets for each of the administrative units can then be transferred to a data base such as LOTUS 123 or dBASE III. Graphic capabilities in these systems allow generated data to be presented graphically on the screen, outline an area of interest, and have a summary of the chosen area in tabular form. For analytical purposes, by directly interfacing the Landsat data with the geographical map data, the classified land cover tabular data may be used to modify the attributes of existing cover type maps and the classified image boundaries may be used to modify the existing geographical maps data boundaries. In this way, the tabular data in the system not only interact with the map data and Landsat classification but also serve as an input to short and long term planning models.

On similar lines but at a broader scale, other types of data can also be integrated into the system. Differing data sets which could possibly be integrated into the information system are listed in Table 3.3. It must be observed that there exists a great degree of commonality in their use by other state departments such as Land, Agriculture or Environment. These departments could all share a common information system. As pointed out by Jupp and Ahmad (1987), commonality of applications justifies a large number of users sharing the same hardware, programs and processing methods. In this situation, each department could define a separate "window" into the system which may only partly overlap with those of other users and may access data not available to others. This commonality provides an opportunity, not only in the multiple use of the same data base, but also of cost savings. This is due to the fact that the cost of integrating data sets in a georeferencing context is very high and cannot afford to be duplicated.

With this structure in view, the remainder of this thesis examines the scope and value of land cover and land cover change information which can be provided by image processing of Landsat data within an integrated data system. Chapter 4 describes the

Table 3.3

Different data sets required for Geographic Information System

Data set	Data Type
Land use/cover	Polygons
Administrative or management zones	Polygons
State, companies and privately owned resource boundaries	Polygons/lines
Conservation areas	Polygon/lines
Transportation network	Lines
Land holdings	Lines
Drainage basin boundaries	Lines
Digital terrain data	Grid
Remotely sensed data	Grid
Soil types	Polygons
Geology	Polygons
Endangered species	Polygons
Inventory statistics	Tables
Climate	Tables
Land degradation	Polygons/Tables

study area, Chapter 5 shows how forest block and Landsat data may be used together to produce base maps and Chapter 6 describes how changes in land cover may be mapped overtime. A summary and conclusions are presented in Chapter 7.

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CHAPTER 4

DESCRIPTION OF THE STUDY AREA

4.1 INTRODUCTION

Selection of a suitable site is a vital part of any research project that aims to use remotely sensed data. Surveying the entire state of Tasmania was ruled out as being too costly and time consuming. A site was sought that would include most of the vegetation characteristics of the state so that successfully developed procedures could be extrapolated to other areas. Site selection was also influenced by the availability of ancillary data that would aid the analysis. In this context, the prime requirement was basic information about vegetation patterns derived from ground surveys or high resolution aerial photographs. It was also realized that additional information on soil types, climate and topography would be valuable.

With these factors in mind, it was decided to use the Scottsdale forestry district (Figure 4.1) as the study area. The region is part of the Wesley Vale forestry reserve and is mostly contained in one Landsat scene. Active commercial logging is being conducted by the forestry companies, namely Australian Pulp and Paper Mills (APPM) and Forest Resources. The forests are harvested for first quality "ash" type hardwoods (*E. delegatensis*, *E. regnans*), second quality "gum" hardwoods (*E. viminalis* and *E. ovata*), and third quality "peppermint" hardwoods (*E. amygdalina*). These wood products are used mainly for wood-chips and both APPM and Forest Resources have woodchip plants at Long Reach in the Tamar valley. Good quality timber is reserved

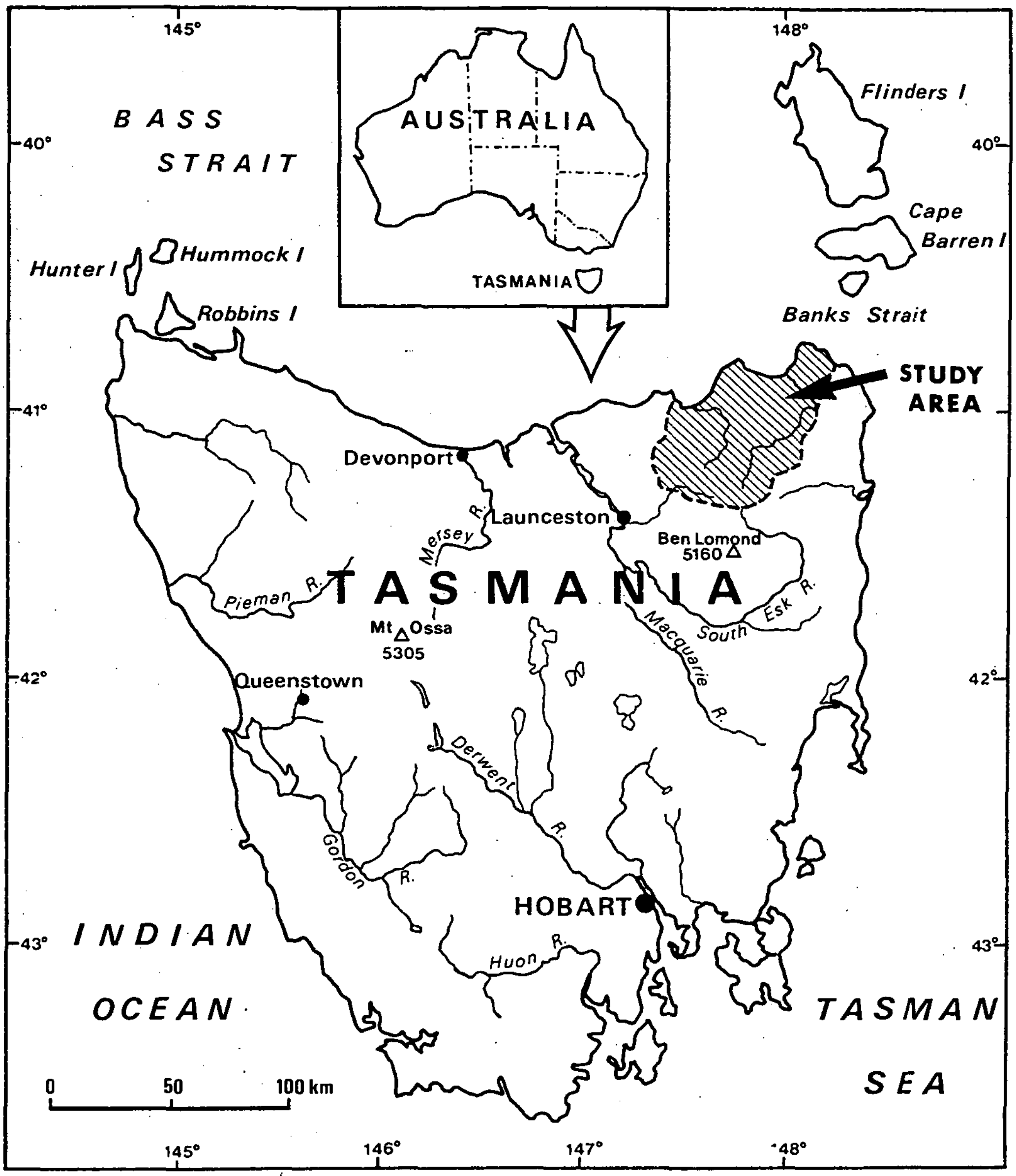


Figure 4.1 : Map showing location of the study area.

as sawlogs and, typically, they may constitute half the merchantable volume in the best of the oldgrowth tall forests (Wood and Kirkpatrick, 1984). Most of the sawlogs in the study area go to private mills not controlled by either of the above two companies. APPM obtains all its timber from Crown land, whilst Forest Resources obtains most of its timber from private land. Both companies and the Tasmanian Forestry Commission maintain active plantation programs. These programs are, in the case of the companies, a necessary condition for logging as specified in the various Acts of Parliament (Wood and Kirkpatrick, 1984).

Considerable ancillary information was available for the region. The main source is the Forestry Commissions photo-interpretation (PI) type maps which are based on aerial photographs (scale 1:15 000 to 1:20 000) and ground surveys. These maps are produced at a scale of 1:25 000 and contain detailed information on various forest types (mature eucalypt, regrowth etc.), as well as height and density information. Table 4.1 lists the main attributes included in these maps. They are not produced on a yearly basis because of the considerable costs involved. However, both PI type maps and a suitable Landsat image were available for the study area during 1980. Added data sources for the area included 1:100 000 topographic maps which were scan digitized to form the basis of a digital terrain model.

Table 4.1 : Major attributes of maps based on aerial photographs interpretation

MATURE EUCALYPT (E)

HEIGHT CLASSES	
E1*	average height more than 76 metres
E1	" " from 55-76 "
E2	" " " 41-55 "
E+3...	" " " 34-41 "
E-3...	" " " 27-34 "
E4	" " " 15-27 "
E5	" " less than 15 "

DENSITY CLASSES	
a	70-100 per cent crown cover
b	40-70 " " " "
c	20-40 " " " "
d	5-20 " " " "
f ..	less than 5 " " " "

TREE COUNT (Dead trees only)	
A*	more than 60 stems per hectare
A	from 40-60 " " "
B	" 25-39 " " "
C	" 15-24 " " "
D	" 2-14 " " "
F	less than 2 " " "

EUCALYPT REGROWTH (ER)

HEIGHT CLASSES	
ER6 ...	average height more than 50 metres
ER5	" " from 44-50 "
ER4	" " " 37-44 "
ER3	" " " 27-37 "
ER2	" " " 15-27 "
ER1	" " less than 15 "

DENSITY CLASSES	
a	90-100 per cent crown cover
b	70-90 " " " "
c	50-70 " " " "
d	10-50 " " " "
f	1-10 " " " "

REGENERATION

N ..... Naturally Seeded	W ..... Wildfire
A .... Artificially Seeded	(72).....Year of Regen. (1972)
N&A .. Part natural & part sown	2 ..... Original O.G. height class (E2)
P ..... Planted	X ...... Original O.G. height class unknown
T ...... Thinned	

MISCELLANEOUS

T .... Secondary species	Wm . Mountain moor
T(W) .. Wattle	Wr.... Bare ground or rock
V .... Cultivation and pasture	Pr ..... Pine plantation
Vz .... Rough grazing	f/d .... Fire damaged
S .... Scrub	o/m .. Over mature
K .... Bracken	c/o ... Cut over
W .... Wasteland	(P) .... Patches
Wg ... Button grass or heathy plain	

RAIN FOREST

	HEIGHT CLASSES
M .... Mature myrtle	1 .... average height more than 37 metres
Mr .... Myrtle regrowth	2 .... " " from 24-37 "
	3 .... " " less than 24 "

4.2 LOCATION AND BOUNDARIES

The study area lies between longitude 146 30 E and 148 30 E. It is bounded in the north by the Bass Strait coastline (Figure 4.5). The southern boundary extends from Pecks hill around the south eastern edge of Patersonia to Ben Nevis, and across to Mount Victoria in the east. The western boundary extends from the Little Forester River in the north to the Denison River and Mount Arthur road in the south. The eastern boundary ranges from Great Musselroe River to Goulds County and follows the Rattler Range across to Mount Victoria. The study area comprises approximately 3500 square kilometers. It extends approximately 75 km from north to south and 68 km from east to west.

4.3 CLIMATE

The Scottsdale district has a mild maritime climate, with a comparatively small diurnal range of temperature. Heat absorption and storage by the sea produces mild winters and cool summers. The maritime influence decreases sharply with distance from the coast and with increasing altitude.

The temperature is greatly influenced by topography and, as a result, is extremely variable. The coast exhibits a smaller range of temperature compared to highland areas. Average annual rainfall ranges from 500 mm on the coast to 1600 mm on the highlands (Figures 4.2 and 4.3). Average annual rainfall recorded at various stations in the study area during the years for which the Landsat scenes were acquired and analysed is given in Table 4.2 and Figure 4.4.

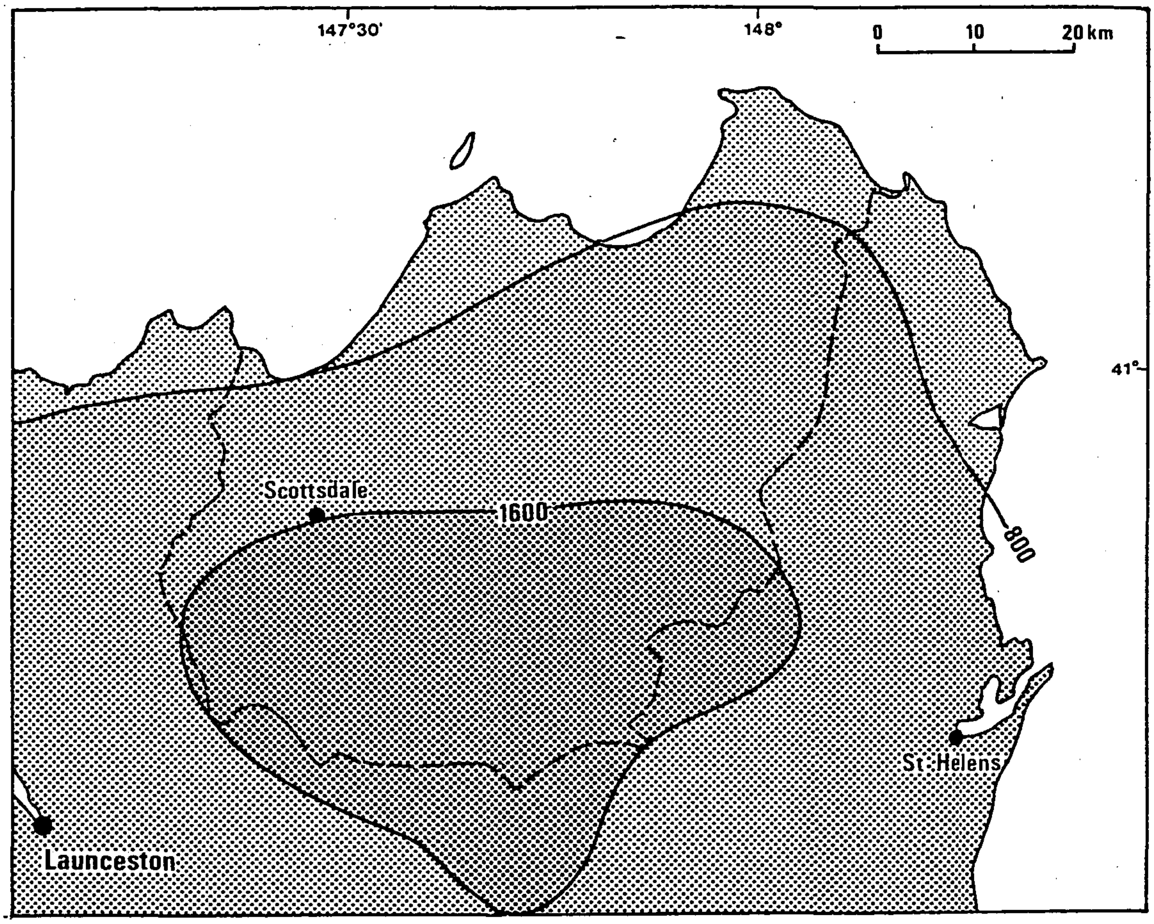


Figure 4.2 : Average annual rainfall (mm) map of the study area.
(Source : Tasmanian Year Book, 1986)

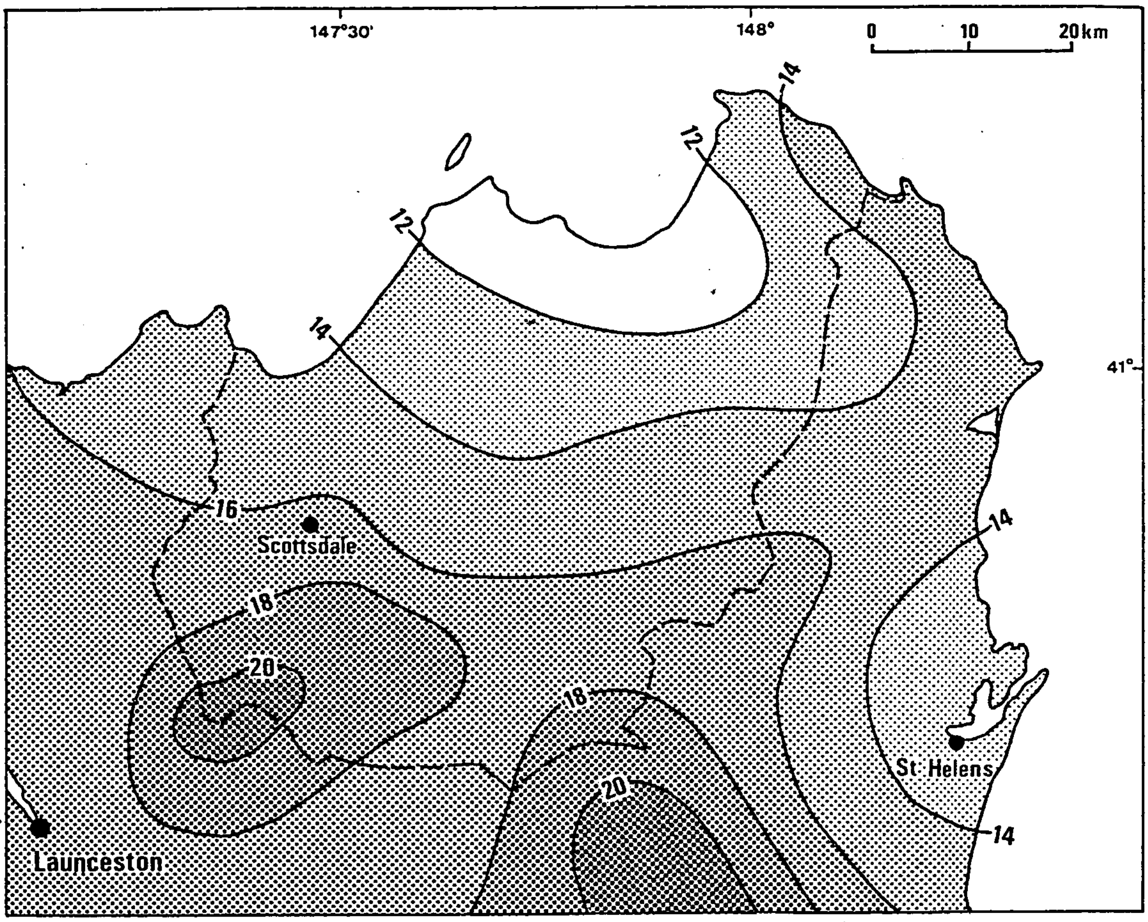


Figure 4.3 : Relative variability of annual rainfall of the study area.
(Source : Pinkard, 1980)

Table 4.2

Mean and actual monthly rainfall (mm) from selected stations in the Scottsdale District

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bridport	**	28	39	42	158	75	89	64	99	78	61	61	42
	***	62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		(43)	(45)	(44)	(69)	(82)	(85)	(90)	(85)	(67)	(70)	(54)	(53)
Jetsonville	**	42	31	43	179	62	80	110	70	78	56	55	38
	***	89	21	103	62	32	36	68	161	103	41	54	47
		(49)	(51)	(50)	(73)	(91)	(101)	(113)	(109)	(89)	(88)	(62)	(59)
Springfield South	**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		(58)	(60)	(68)	(95)	(136)	(134)	(152)	(158)	(129)	(123)	(86)	(82)
St. Patrick River	**	32	20	47	173	88	91	152	187	185	47	47	71
	***	60	21	200	110	75	75	114	245	238	70	73	69
		(59)	(64)	(69)	(108)	(134)	(154)	(183)	(175)	(137)	(117)	(89)	(82)
Ringarooma	**	79	32	57	187	102	99	127	147	152	79	44	70
	***	69	34	169	85	51	81	96	223	239	54	96	81
		(63)	(59)	(69)	(92)	(118)	(137)	(158)	(146)	(123)	(112)	(80)	(76)
Diddleum Plains	**	60	25	62	195	137	133	162	175	245	81	101	92
	***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		(73)	(78)	(78)	(121)	(149)	(151)	(212)	(190)	(146)	(131)	(108)	(103)
Myrtle Bank	**	12	22	20	184	162	50	125	43	118	104	0	65
	***	102	17	195	128	57	57	N/A	N/A	N/A	N/A	N/A	N/A
		(65)	(75)	(75)	(117)	(156)	(168)	(196)	(197)	(143)	(117)	(103)	(92)
Nabowla	**	51	23	42	178	60	95	146	114	126	40	78	47
	***	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		(48)	(56)	(53)	(78)	(93)	(100)	(130)	(121)	(93)	(92)	(73)	(69)
Tomahawk	**	31	26	43	125	53	80	56	85	78	68	68	39
	***	52	29	85	43	27	35	68	154	91	28	46	53
		(35)	(33)	(62)	(73)	(83)	(69)	(89)	(90)	(71)	(60)	(63)	(57)
Winnaleah	**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	***	79	42	142	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		(44)	(59)	(48)	(110)	(97)	(101)	(114)	(130)	(98)	(94)	(72)	(71)
Scottsdale	**	45	27	50	204	90	90	161	114	138	67	73	42
	***	80	26	135	77	50	54	88	200	157	53	58	67
		(59)	(39)	(72)	(105)	(113)	(110)	(135)	(117)	(109)	(88)	(77)	(74)
Moorina	**	46	37	26	174	120	79	109	101	132	84	79	70
	***	77	04	147	138	130	69	85	86	140	62	72	07
		(55)	(64)	(69)	(89)	(109)	(127)	(126)	(129)	(102)	(100)	(80)	(74)
Gladstone	**	33	25	44	122	78	75	57	94	81	73	72	53
	***	46	10	95	62	05	19	76	143	101	N/A	N/A	N/A
		(39)	(59)	(57)	(75)	(83)	(90)	(91)	(84)	(73)	(77)	(61)	(65)
Pioneer	**	37	35	20	140	92	74	91	94	112	73	87	62
	***	73	38	138	62	29	48	101	198	156	36	69	71
		(45)	(56)	(62)	(80)	(97)	(106)	(112)	(106)	(88)	(93)	(67)	(69)
Eddystone Point	**	29	52	124	95	75	75	25	58	63	89	61	95
	***	43	47	130	49	15	30	95	191	112	31	49	67
		(41)	(50)	(61)	(68)	(72)	(82)	(77)	(74)	(65)	(75)	(61)	(61)

** Actual rainfall in 1984
*** Actual rainfall in 1980
( ) Mean rainfall for the period 1912 to 1984
N/A Not available
(Source: Bureau of Meteorology, Canberra).

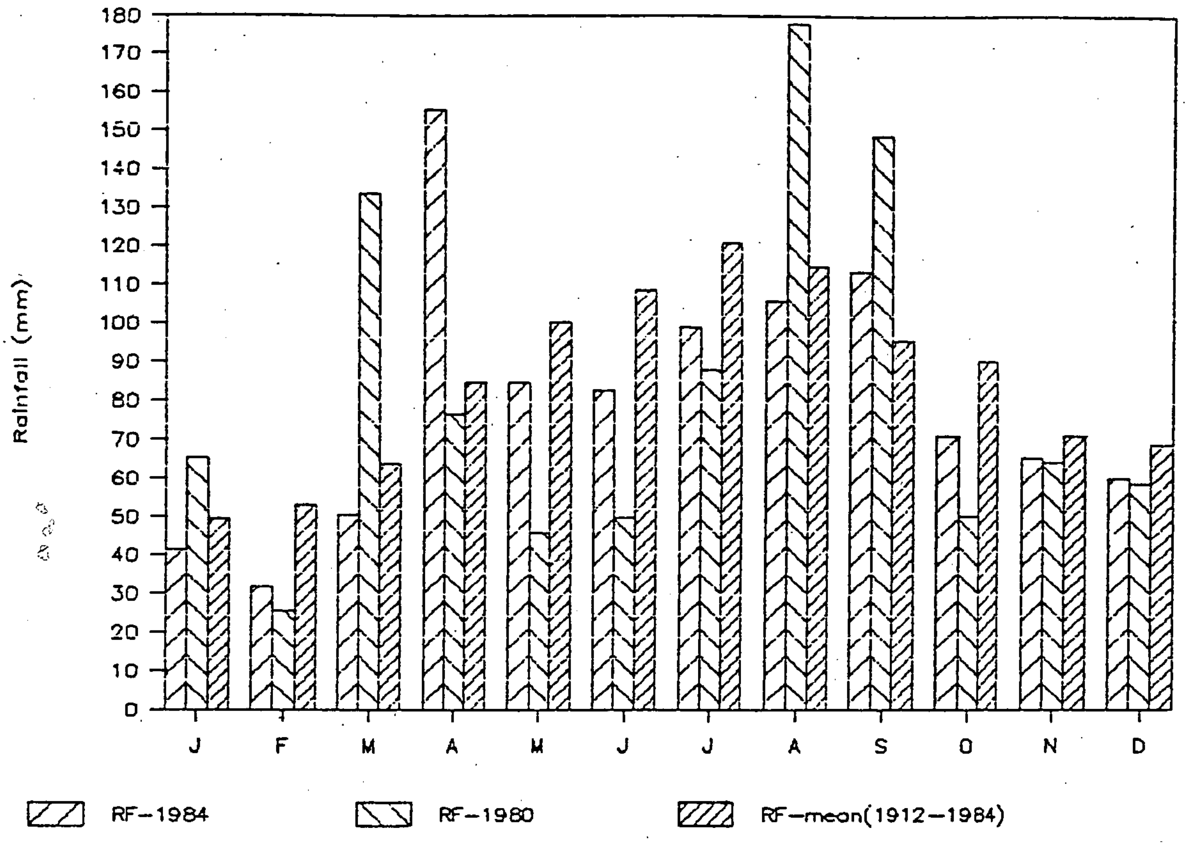


Figure 4.4 : Bar diagram showing monthly rainfall for the average of fifteen stations in the Scottsdale district. Note the above average rainfall for April 1984.

As mentioned in Chapter 5, Landsat scenes taken at different seasons may show distinct differences. In this study two Landsat scenes, one taken in early winter (May) and one in early summer (November) were selected. As can be seen in Figure 4.4 average and actual rainfall during the month of April and May in the district is significantly higher than during the month of October and November. Higher rainfall and lower evapotranspiration increase the wintertime soil moisture and as a result signatures observed on the remotely sensed images are affected. Seasonal differences in such factors as sun angle or soil moisture could in turn complicate or ease the identification of some of the land cover classes. For example, in this study it was found that bare soil, urban areas and poa grass were difficult to identify in the winter image, as compared to the summer image. These affects are discussed in detail in Chapters 5 and 6.

4.4 PHYSIOGRAPHY

The study area contains a wide range of land forms including mountains, hills and plains. Prominent features are the coastal plains and the north eastern highlands. As described by Davies (1965) most of the northern area features continuous undulating lowland plains, where emerged platforms have been extended seaward by coastal accretion. The north eastern coast consists of a belt of dunes fringing the sea shore. "Blow-out" dunes extend inland for up to four kilometers in many localities. A well marked trough lies behind the dunes, and gradually rises in a series of steps and scarps to the more hilly and mountainous areas further inland (Stephens and Cane, 1973). Generally the mountains are dolerite capped and plateau-like with a considerable number reaching elevations in excess of 1000 meters. The principal topographic features in the study area are Mount Horror, Mount William, Mount Cameron, Mount Arthur, Mount Maurice and Mount Victoria. The major rivers flowing in the area are Great Musselroe, Ringarooma, Boobyala, Tomahawk, Pipers and Great Forester river (Figure 4.5).

4.5 GEOLOGY

The geology of the Scottsdale district varies greatly. The principal substrata consist of Quaternary deposits, Jurassic dolerite and Devonian granite (Figure 4.6).

4.5.1 QUATERNARY DEPOSITS

Recent and Pleistocene deposits cover extensive areas along the coast and are important for agriculture. Areas of glacial and periglacial deposits occur in the higher parts (Mt Barrow, Mt Arthur).

The dolerite talus around the mountains consists of variably sized angular to sub-rounded blocks. Talus formed from other rock types (Triassic, Permian) also occurs. Scree found at the base of the dolerite cliffs consists of unweathered dolerite fragments (Pike, 1973).

Extensive alluvial deposits of sand, silt and clay laid down by the present major river systems are also found throughout the district (McClenaghan and Baillie 1975). The most extensive areas of these deposits are composed of sand and clay containing

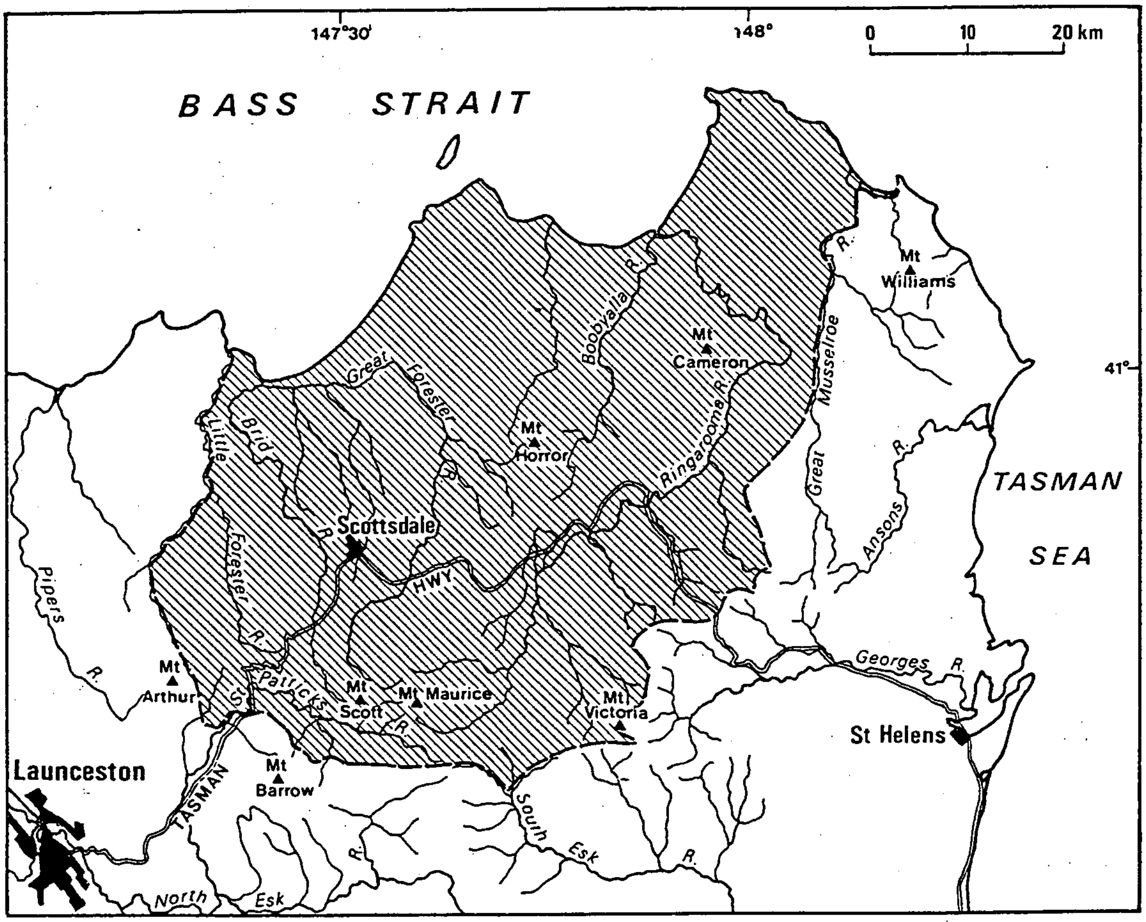


Figure 4.5 : Physiographic map of the study area.

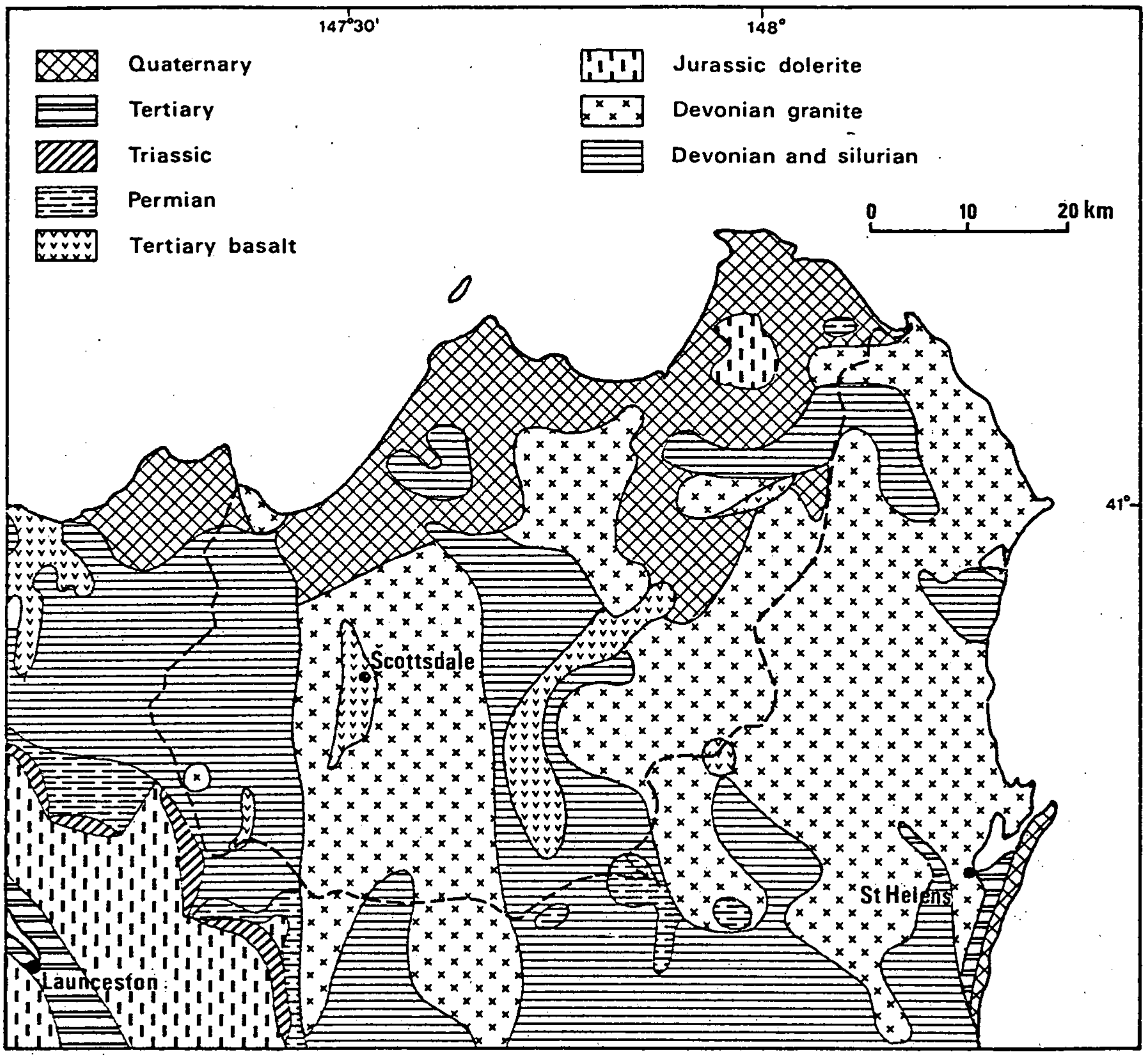


Figure 4.6 : Geological map of the study area.

abundant quartzite pebbles.

4.5.2 JURASSIC DOLERITE

Large scale intrusions of Jurassic dolerite into Permian and Triassic sediments are evident in a large part of the district. These intrusions are in the form of thick sills and sheets of massive, medium-grained dolerite (McClenaghan and Baillie 1975). They occur in the form of a large undulating sheet stretching from northern areas to the South Esk river. The highest areas are capped with dolerite (Mt Barrow, Mt Arthur and Mt Victoria).

4.5.3 DEVONIAN GRANITE

As described by McClenaghan and Baillie (1975), upper Devonian granite and granodiorite outcrop a large part of north eastern Tasmania, intruding the Mathinna Beds. These rocks occur in three main masses, namely the Scottsdale batholith, the Blue Tier batholith and the Ben Lomond batholith.

The Blue Tier batholith is predominantly a damellite-granite with small areas of granodiorite. The Scottsdale batholith is almost exclusively granodiorite, while the Ben Lomond batholith is almost exclusively adamellite-granite.

The Scottsdale batholith extends from Bridport southwards to the northern flank of Ben Lomond. The Ben Lomond batholith extends from the Ben Lomond Plateau southwards to the South Esk river. The Blue Tier batholith covers an extensive area in the far North east of the region.

4.6 SOILS

The spectral response of soil types and plant canopies largely determine the patterns visible on remotely sensed imagery. Consequently, any land cover classification based on such imagery is also dependent on these spectral responses. Various studies have shown that soil spectral signatures differ with soil moisture, colour, texture and soil minerology (Bowers and Hanks, 1965; Stoner and Baumgardner, 1981). For example, saline and sandy soils along rivers and coast lines, when dry, are highly reflective in all bands whilst black fallow soils have a low reflectance. When observed in different seasons or at different times of the year, the same soil types can show considerable variation in spectral response. Therefore, detailed information about various soil types in the study area is required to accurately interpret remotely sensed imagery.

Following Northcote et al. (1975), the soils of the study area have been classified into organic, uniform, gradational and duplex soils (Figure 4.7).

4.6.1 ORGANIC SOILS

No true organic soils are found in the area, although some clay soils have a shallow, highly organic surface layer.

4.6.2 UNIFORM TEXTURED SOILS

These are of two types i.e sandy soils and clay soils.

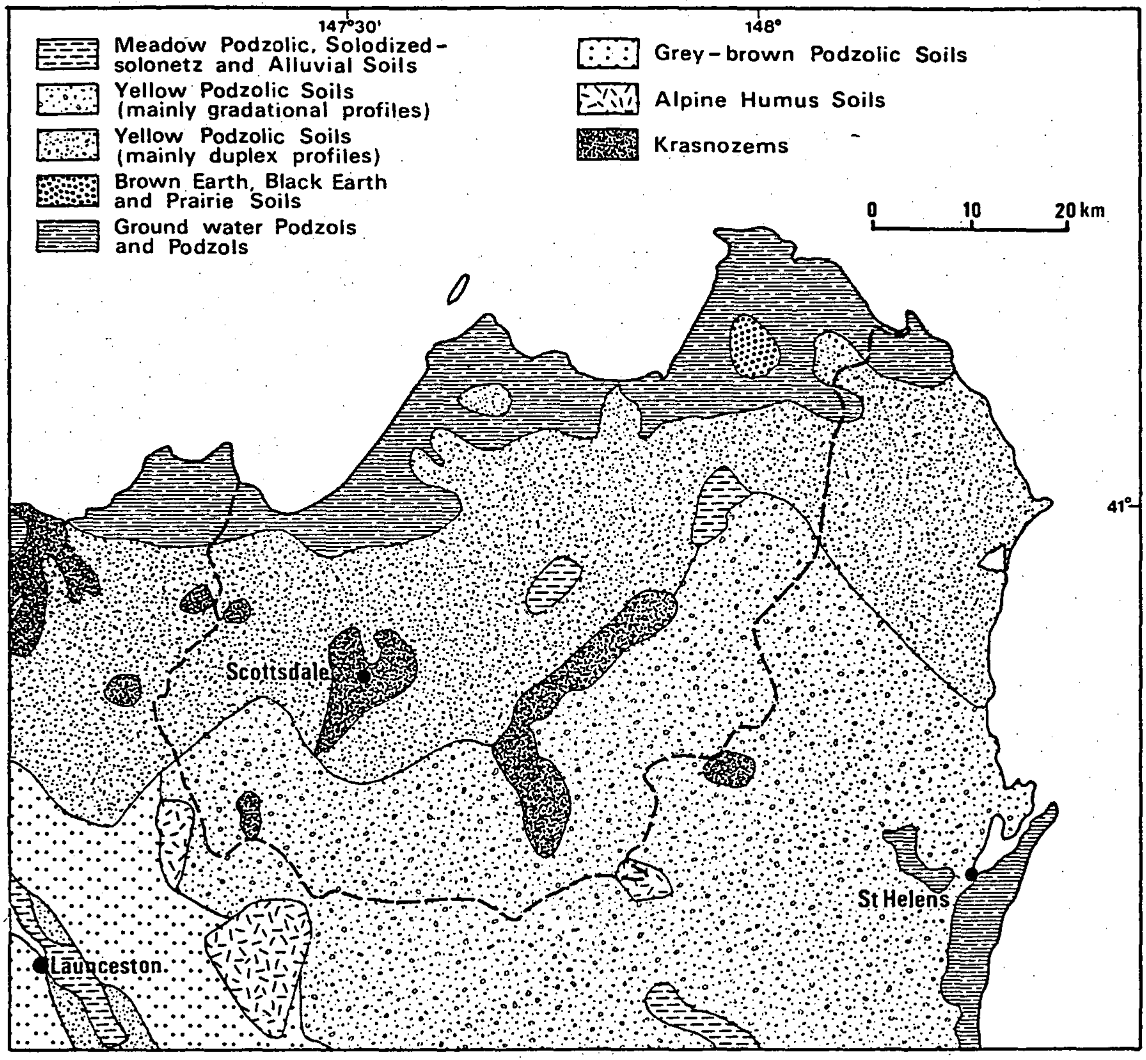


Figure 4.7 : Soil type map of the study area.
(Source : Davies, 1965)

4.6.2.1 SANDY SOILS

Coastal dunes and beaches of the area are characterized by weakly differentiated calcareous sands. These are generally yellow or pale yellow in colour whilst light to dark grey deep siliceous sand covers coastal plains, very old sand dunes and areas along the ridge formed on Quaternary materials. Grey to brown sandy soils are observed in plains of Quaternary deposits (Stephans, 1939).

4.6.2.2 Clay soils

These soils have variable colour, with whole colours dominating individual sites. They occur mainly along drainage lines, swales and on the flood plains of the low hills and plains formed on Quaternary deposits and Devonian granite and granodiorite. The principal colours are grey, black and brown. Black, very dark grey and grey colours occur mainly on Quaternary deposits. Yellowish brown and brownish yellow clays are found mainly on Devonian granite and granodiorite.

The mottled clays occur mainly on the lower slopes or drainage lines of hills and plains formed on Quaternary deposits. Soil colours are predominantly dark grey and grey with strong brown or brownish yellow mottlings (Pinkard, 1980).

4.6.3 GRADATIONAL SOILS

Most of the district is covered by soils with gradational profiles. These are mostly less than 1.5 meters deep and have moderate permeability. Soil colour is variable and consists mostly of whole colours with little incidence of mottled profiles.

The whole coloured gradational soils occur mainly on the crests and slopes of hills and mountains formed on Devonian granite and granodiorite deposits. These soils are generally brown and yellowish brown in colour, and are found mainly on the Devonian country. Those found on the granite and granodiorite have a gravelly or gritty clay loam surface and are generally stony (Pinkard, 1980).

Mottltd gradational soils occur predominantly on the lower slopes and swales of low hills and hills formed on Quaternary deposits. The principal colours are grey and yellowish brown with mottlings of strong brown, grey yellowish brown and greyish brown. Generally, the surface texture of the mottled gradational soils on the Quaternary deposits is a clay loam.

4.6.4 DUPLEX SOILS

Duplex soils, mostly of mottled profile occur on plains and the mid to upper slopes of low hills, formed on Quaternary deposits. The principal colours of duplex soils found in the area are yellowish brown and grey. The surface texture of these soils is generally a sandy loam (Nicolls and Dimmock, 1965).

Whole coloured duplex soils are found mainly on plains or low hills formed on Quaternary deposits. These soils are characterised by a large proportion of gravel and stone. Their colour is highly variable although the principal colours are brownish yellow, yellowish brown and deep brown. The surface texture of whole coloured duplex soils is a gravel clay loam which occurs on the Quaternary deposits of the area (Stephans and Cane, 1937).

4.7 VEGETATION

The vegetation of the study area, like most of Tasmania, has been fundamentally affected by people. Before European settlement, aborigines had an important effect on vegetation through their control and use of fire (Singh et al., 1980). Robinson (in Plomley, 1966) described how aborigines at that time used fire consistently for hunting and for keeping their travel routes and camping areas free of undergrowth.

The advent of European settlement has had an enormous impact on the appearance of the landscape including the structure and composition of vegetation. Large areas of native forest have been cleared and converted to agricultural use. New plants and animals have been introduced and the deliberate and accidental use of fire has had a strong impact on vegetation patterns. Similarly, the extraction of timber from the forests, in the early days by selective logging and, more recently, by clearfelling techniques, has imposed a significant anthropogenic imprint on the forests. This has been exacerbated by the gradual deployment of reafforestation practices which have tended to emphasize species of commercial value and produce changes in the composition of the forests.

The vegetation of the Scottsdale district (Figure 4.8) varies structurally and floristically in response to variations in climate and soil type. This is particularly so with the

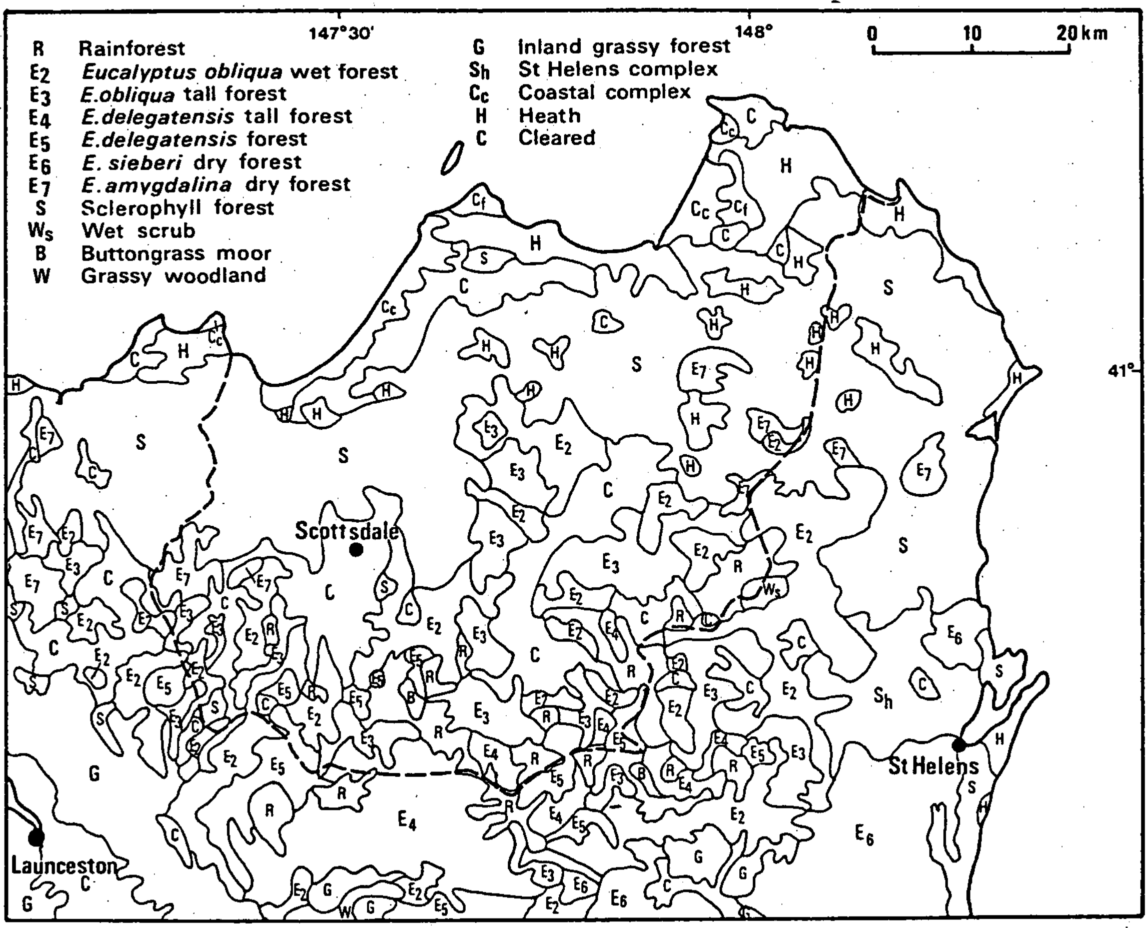


Figure 4.8 : Vegetation types map of the study area.
(Source : Kirkpatrick, 1984)

eucalypt species which show a mosaic distribution. The influence of man has made it difficult, in many areas, to determine the height and density of the original vegetation stands. It would appear from climatic conditions, that prior to settlement by Europeans most of the area was covered by forests. The coastal areas were probably covered by sclerophyll forests and the higher rainfall inland areas by rainforests. Jackson (1965) points out that rainforest is likely to be the climax vegetation in areas with annual rainfall in excess of 1400 mm, and particularly in areas with summer rainfall exceeding 50 mm per month. However, frequent firing has resulted in the widespread occurrences of vegetation disclimaxes.

The main structural forms of vegetation in the area are open-forests, woodlands and scrub. Other forms include shrubland, heath, and grassland.

4.7.1 FOREST COMMUNITIES

Examination of current vegetation communities in the Scottsdale district shows a broad spectrum of types. At one end are the more or less treeless plains dominated by Poa labillarderi. These occur mainly in localities such as Paradise Plains and Diddleum Plains. At the other end of the vegetation spectrum are closed temperate rainforests dominated by Nothofagus cunninghamii with variable components of Phyllocladus asplenifolius and Atherosperma moschatum (Ellis, 1985). Between these two extremes are communities dominated mainly or entirely by sclerophyll forest over a ground cover of grass or ferns and a highly variable understorey of shrubs. Acacia dealbata and

Leptospermum lanigerum occur both as trees of intermediate height between eucalyptus and shrubs and, on some sites, as dense pure stands. Eucalyptus also occur as emergents over a closed rainforest.

The relationship between the rainforest and sclerophyll forest (dominated by eucalyptus) is influenced by fire, soil fertility and aspect (Jackson, 1965). In areas of high rainfall, eucalyptus regenerate after severe disturbance such as fire and windthrows. In the absence of fire, an understorey of rainforest species develops between eucalyptus, which themselves fail to regenerate beneath the closed canopy and are eliminated when they die of old age. The rainforest is reduced or temporarily eliminated if a fire occurs during the life of a eucalyptus stand. The resultant condition of fire and sunlight allows the seedling to germinate and grow (Gilbert, 1959).

The most abundant structural forms amongst the sclerophyll forest are the open forests and tall open forests. In general, there are two types: dry sclerophyll vegetation which includes low woodland and open forest and wet sclerophyll vegetation which is usually tall open forest but may also include tall open woodlands. However, there is a degree of overlap because some wet sclerophyll forests have trees that are not tall and some dry sclerophyll forests have trees that are very tall.

In the north eastern region, these sclerophyll forests occur mainly on gradational and duplex soils which have formed on dolerite, granite, granodiorite, and sandstone deposits. The open forests give way to the tall open forests in areas of higher rainfall and elevation.

By far the most dominant eucalyptus are E. obliqua, E. amygdalina and E. viminalis. E. obliqua is replaced by E. delegatensis in areas of higher rainfall and elevation. E. regnans is common in sheltered situations on deep, well drained soils. The distribution and dominance of these eucalyptus depends on the climate, soil and aspect.

In the dry sclerophyll forest, the shrub layer is low and sparse compared with the tall dense layer in the wet sclerophyll forest. The principal shrub layer species are Acacia spp, Casuarina spp, Leptospermum scoparium, Melaleuca ericifolia, and Epacris spp. As the rainfall increases, Helichrysum spp, Bedfordia spp, Olearia spp, Pomaderris apetala and Zieria arborescenis become the dominant species.

Closed forests and tall closed forests occur in areas of high rainfall. These are mainly composed of rainforest species, but may be mixed or sclerophyll forests. They occur mainly on gradational soils. The principal eucalyptus in these closed sclerophyll forests are E. obliqua, E, delegatensis, E. regnans and E. globulus. The closed rainforest is dominated by Nothofagus cunninghamii and Atherosperma moschatum. For further description of these communities see Duncan and Brown (1985).

4.7.2 WOODLAND COMMUNITIES

The principal structural forms are woodlands, open woodlands and low woodlands. They occur mainly in areas of low rainfall and high fire frequency. They are found on duplex and uniform-textured soils which have formed on Quaternary and Jurasic dolerite deposits in the area.

Eucalyptus are the main components of these woodland communities, although the tree density is low. The dominant species are E. amygdalina, E. regnans and E. dalrympleana. The main cunderstorey plants include Acacia spp, Casuarina spp, Banksia marginata, Exocarpus cupressiformis and Melaleuca ericifolia.

4.7.3 SCRUB AND HEATH COMMUNITIES

The scrub and heath communities are mainly found in coastal areas on poor soils where forest growth is limited. The principal structural forms are open scrub, open heath and closed heath. The scrub communities are found mainly on uniform-textured soils which have formed on Quaternary deposits. These deposits includes coastal sands and alluvium. Acacia sophorae, Banksia marginata and Epacris dominate the scrub vegetation on the stabilised coastal sand dunes. Casuarina stricta, Acacia spp, Melaleuca spp, Xanthorrhoea australis, Banksia marginata, E. amygdalina and E. regnans and E. epacris are common on the coastal sand plains. On the high country, the gradational soils support a closed heath (alpine) of Leptospermum rupestre, Richea scoparia, Orites revoluta, Olearia spp, and Orites acicularis.

4.7.4 MINOR VEGETATION COMMUNITIES

These include shrublands, sedgelands and tussock grasslands. The shrubland community, consisting of low shrublands and low open shrublands, is mainly found in poorly drained areas such as flood plains. Uniform textured soils on Quaternary deposits support these communities. Like shrubland vegetation, the sedgelands are found mainly in poorly drained situations, on uniform textured soils on Quaternary deposits. The tussock grassland vegetation is found on the unstable coastal sand dunes.

4.8 SUMMARY

This Chapter has discussed various characteristics of the study site. The emerging pattern is one of high variablity in many features of the physical environment. The topography varies from broken mountainous country with isolated peaks reaching elevations of over 1200 meters above sea level, to flat coastal plains dominated by sand dunes. In the district, yearly rainfall pattern varies, which ranges from 800 mm per year along the coast to 1600 mm per year in high elevation areas. The complex influence of elevation, climate and rock type is evident in the distribution of soils and vegetation. In particular the forest type varies from rainforest species through E. amygdalina, dominated dry forest to coastal heath.

Superimposed on this pattern is the very marked imprint of human activity. Many areas have been cleared for agriculture human settlement. There are plantations of introduced softwood species such as Pinus radiata which are harvested regularly. Others areas are logged for native hardwoods. There is regeneration occuring from even aged native forests, from native forests of varying ages and varying kinds as well as from other vegetation associations. The pattern is thus influenced by an amalgamation of physical and human factors which interact with each other. This complexity means that the region contains elements of most of the major vegetation associations that occur within the state as a whole.

CHAPTER 5

5.0 LAND COVER CLASSIFICATION BASED ON LANDSAT MSS DATA

5.1 THE CONCEPT OF LAND USE/COVER CLASSIFICATION

For general land cover mapping using remotely sensed data, it is essential to distinguish between the closely linked terms of landform, land cover and land use. Remotely sensed images from space altitudes show landform and landform patterns by shading. Relief, slope, stream channel occurrence and other geomorphological patterns are etched into the Landsat imagery by the effects of the relatively low sun angles at the time of the satellite overpass. These landform elements in turn influence the land cover and land use of a region.

There are many opinions on the guidelines for distinguishing between land use and land cover (Graham, 1944; Burley, 1961 and Osbern, 1968). One definition that has wide acceptance is that land use refers to man's activities on land which are directly related to the land (Clawson and Stewart, 1965). Land cover on the other hand, describes the vegetative, topographic and artificial structures covering the land surface (Burley, 1961).

Land use and land cover are closely related but it is important to note that remote sensing systems do not record activity directly. Characteristics of the land surface, whether natural or artificial, determine the radiance responses which are detected by the remote sensors on board aircraft or satellites. Information about land use activities is inferred from visually or numerically derived information about land cover.

In this thesis, land cover is assumed to describe the natural and man made resources covering the land surface. Land use defines the activity on the area in question, and land classification refers to a systematic division of land cover and therefore, (indirectly) land use, into classes or groups.

5.2 GROUND RECONNAISSANCE SURVEY

A field survey of the study area was conducted prior to image classification. This was done so as to gain some familiarity with the study area and to determine the number of land cover classes which could later be identified using remotely sensed data. A rectified colour composite image of the Landsat raw data covering the entire Scottsdale district was produced at a scale of 1:100 000 on an Applicon inkjet plotter and taken to the field. During this visit, major land cover types of the study area which could be easily identified were marked on the laminated Landsat image. This step was accomplished with the help of field staff members of the Tasmanian Forestry Commission who had extensive knowledge of the study area.

In some cases a difference in the colour or texture of the image was related to information gained from photo-interpretation maps. The vegetation characteristics and other relevant information such as landform pattern and forest density were also recorded for each of the sites visited during this trip. Some of the major land cover types of the study area are illustrated in Figures 5.1.1 to 5.1.23. Low, medium and high density referred in these figures imply less than 40 percent, 40 to 70 percent and greater than 70 percent crown cover respectively.

Figure 5.1.1 : Young pine plantation (2-4 years old).

Figure 5.1.2 : Young pine plantation (4-6 years old).

Figure 5.1.3 : Advanced pine plantation (25-30 years old).

Figure 5.1.4 : Mixture of young pine, wattle trees and dolly bush.

Figure 5.1.5 : Logging of pine plantation.

Figure 5.1.6 : Cable logging coupe in old pine plantation with cleared agricultural land in foreground.

Figure 5.1.7 : Rainforest with fern understorey and dead Myrtle trees.

Figure 5.1.8 : Rainforest with shrubs and grasses in the foreground.

Figure 5.1.9 : Tree ferns and blackwood with bracken in the foreground.

Figure 5.1.10 : Mixed forest (Eucalyptus and rainforest).

Figure 5.1.11 : Mixed forest (Eucalyptus and rainforest).

Figure 5.1.12 : Dense wet sclerophyll forest (oldgrowth).

Figure 5.1.13 : Medium dense wet sclerophyll forest with wattle and scrub understorey.

Figure 5.1.14 : Dense dry sclerophyll forest with agricultural land in foreground.

Figure 5.1.15 : Medium dense dry sclerophyll forest.

Figure 5.1.16 : Button grass.

Figure 5.1.17 : Fire burnt button grass.

Figure 5.1.18 : Fully developed agricultural land.

Figure 5.1.19 : Fully developed barish agricultural land.

Figure 5.1.20 : Logging in wet sclerophyll forest.

Figure 5.1.21 : Sand dunes.

Figure 5.1.22 : Sand dunes.

Figure 5.1.23 : Eucalyptus dieback. See Eller, (1985) for a discussion of the dieback problem.

5.3 THE TECHNIQUE OF LAND CLASSIFICATION

In general, an area of land may be described in terms of many attributes which can be classified according to some objective. The classification may be needed to label various objects on the land, to gain information about the objects, or to allow generalizations to be made about the objects. As Grigg (1965) pointed out, classification is the grouping of objects into classes on the basis of properties or relationships they have in common. There are two different ways of grouping the objects. Firstly, each object may be examined individually and related to other objects according to some characteristics. For example, parcels of forest land, all having the same crown density may be assigned to different classes on the basis of their stocking (number of trees in an area). These classes may then be further aggregated into larger classes on the basis of crown density. All density classes may be classified as being wet sclerophyll or dry sclerophyll forests, and these two classes may be grouped together to form a single class, forest land.

In such an approach, generally called the inductive logical approach, the entire range of possibilities of forest type is not analyzed, nor are all other properties considered which could be used as criteria in the classification procedure.

In the second case, which is generally called the deductive logical approach, a class is created in which maximum possible occurrences of it are considered (in our case land). This class is then subdivided on the basis of the need for the classification (in our case land use/cover types). In this type of approach, the entire range of uses and cover types are considered before classes are created. This makes such a classification applicable to the entire area or region.

In practice, the classification procedure often uses a combination of both approaches. Regarding land (deductive approach), the interpreter gains knowledge about the existing land use and cover by examining aerial photographs, satellite images or existing vegetation or land use maps. After examination, the interpreter formulates a plan for land use/cover classification either by aggregating or dividing a number of observed classes. During the examination the interpreter also ascertains which type of land use/cover class of value to the end purpose of the classification can be interpreted from the data (inductive approach).

In this study, various land use/cover classes for mapping were determined from the information gathered during the reconnaissance survey and from careful examination of the existing vegetation type maps, photo-interpretation maps and aerial photographs. Moreover, various researchers who had good knowledge of the region were also consulted. As a result of this inductive-deductive procedure, two levels (Level I, and Level II) of land use/cover classes were selected. This procedure is, however, quite independent of remote sensing. It expresses the interpreter's view of the area for the purposes of his interpretation. Later, the way in which this logical classification can be associated with a computer based spectral classification will be of particular concern. Details of the land use/cover classes selected for this survey are given in Table 5.1.

5.4 LANDSAT MSS DATA SELECTION AND ACQUISITION

The selection of high quality imagery is an important factor in the successful application of Landsat MSS data. Among the criteria to be considered are cloud cover, image quality (which must be free of errors including six line banding), atmospheric haze, year of acquisition, season and specific month. The season has a strong influence on the appearance of the vegetation. It has been observed that some land cover types which can be distinguished at one time of the year are extremely difficult to identify or separate at another time. Among other factors, Holben and Justice (1980) pointed out the significance of time of year on the observed features of a Landsat image. This is because the sun elevation and azimuth will influence the spectral response of the target surface. This applies particularly to rugged terrain where the amount of energy intercepted may vary markedly. The following procedure has been adopted in this study for the selection of Landsat imagery.

1. Determine the flight path and row of the required imagery from the Landsat index map of Australia,
2. Inspect the Australian Centre for Remote Sensing (ACRES) image search program and view the paper prints or coloured microfiche to determine the location of cloud cover and the general quality of the image,
3. Select the images taking into consideration the above mentioned criteria. It is desirable in studies of change

TABLE 5.1

The list of classes selected in the classification scheme

Level I	Level II
1 Pine plantation	- Young pine (planted after 1980) - Old pine (planted upto early 70's)
2 Rainforest	
3 Mixed forest (Eucalyptus with dense rainforest understorey	
4 Wet sclerophyll forest	- Regrowth and oldgrowth eucalyptus with a myrtle, wattle and scrub understorey - Medium dense oldgrowth eucalyptus with a wattle and scrub understorey - Leptospermum-Melaleucascruby margin forest
5 Dry sclerophyll forest	- Dense with broad leaf shrub understor at margin of wet sclerophyll - Medium dense eucalyptus with scrub understorey - Dense with scrub understorey - Moderately open Casuarina Littoralis in areas of rapid drainage - Closed prickly schrub understorey in poorly drained areas
6 High altitude Moorland	
7 Grassland	

Table 5.1 (cont.)

8 Coastal heath	- Wet coastal heath.
	- Burnt coastal heath.
9 Agricultural/pasture land	- Fully developed with dense crops and forage
	- Fully developed with sparse crops and forage
	- Recently cleared barish land.
	- Poorly cleared land with remnant eucalyptus
	- Very rough grazing land (disturbed ground surface)
10 Fire burnt patches	
11 Logged areas	
12 Bare ground	
13 Sand dunes	
14 Tin mining areas	
15 Urban areas and farm buildings	
16 Dieback	

detection to select images from as close to the same time of the year as possible to eliminate the added complication of marked changes in shadowing effects.

In practice, the choice may often be much simpler than the above description suggests. This is mainly because of the low availability of relatively cloud free scenes, especially in the cloudy environment of Tasmania. Because of the time and financial constraints imposed during this project, only two scenes were selected (Figures 5.2 and 5.3). Details of the scenes selected for analysis are given in Table 5.2.

Table 5.2

Details of the scenes selected for analysis

Data type	Date acquired	Image identification number
Landsat 2 MSS CCT'S	09 November 1980	22118-23092
Landsat 5 MSS CCT'S	04 May 1984	23192

Landsat imagery are characterized by several types of radiometric and geometric errors which need to be removed before the data can be compared or integrated with GIS attributes. Digital analysis usually begins with certain preprocessing techniques which correct these problems. In this study, the data were preprocessed for radiometric striping, stretching or colour enhancement, atmospheric effects, removal of clouds and ocean, and image rectification. For details see Appendix A3.0.

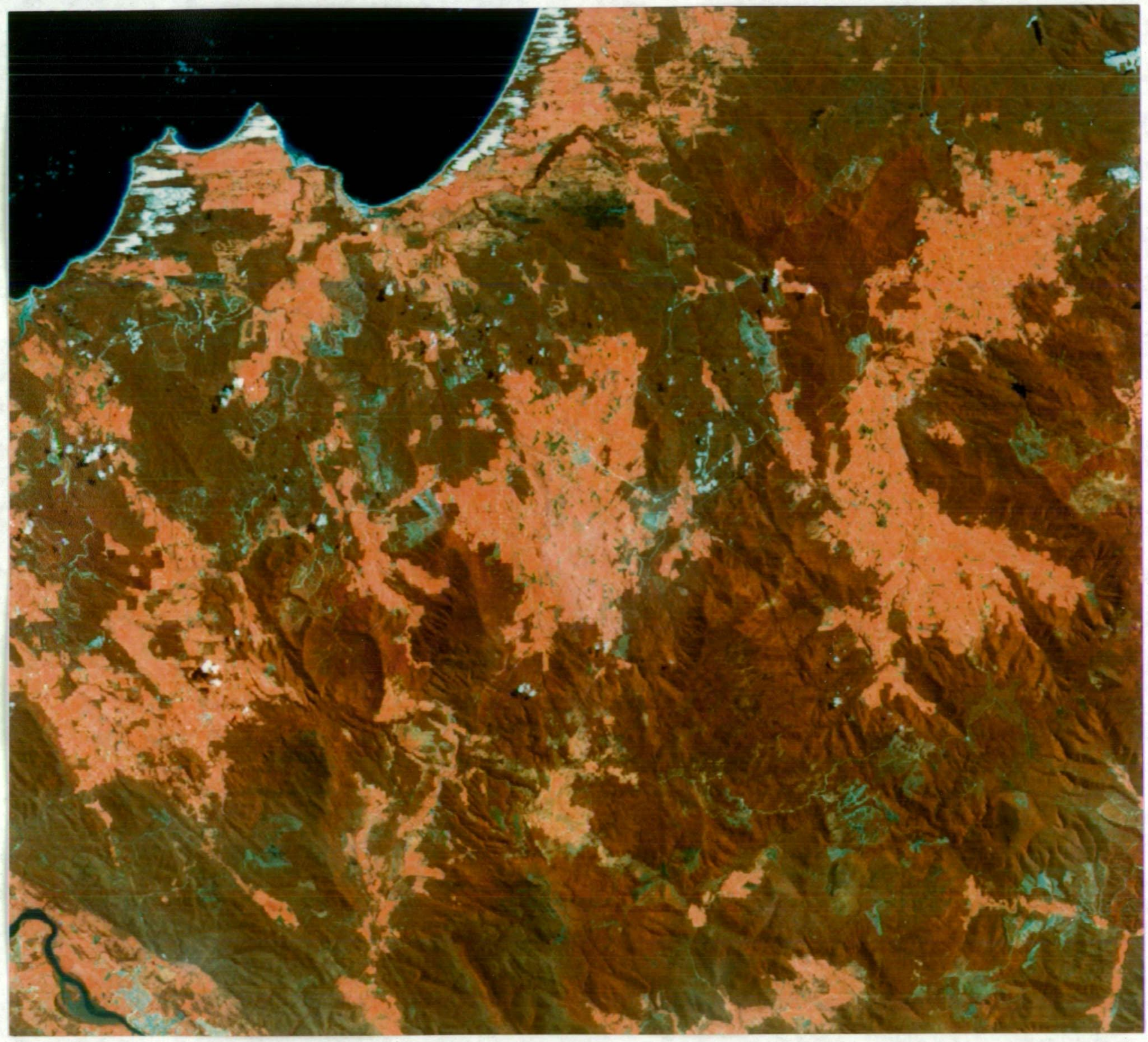


Figure 5.2 : A false colour composite image of the study area - 1980

Figure 5.3 : A false colour composite image of the study area - 1984. The area used for illustration purposes is shown in the overlay.

Figure 5.3 : A false colour composite image of the study area - 1984. The area used for illustration purposes is shown in the overlay.

5.5 DIGITIZING DISTRICT AND FOREST BLOCKS BOUNDARIES

5.5.1 NEED FOR DIGITIZING

Geographic data are usually collected by administrative or forest blocks with distinct boundaries. Therefore, any remotely sensed data must be related to these blocks or to sub-unit level data, by associating each pixel with the administrative unit to which it belongs. This procedure has distinct advantages in remote sensing. Firstly, it may increase the homogeneity of the data set and enable separation of different features which are spectrally similar. This leads to an improvement in classification accuracy. Secondly, there is a significant reduction of variation within each of the smaller strata (i.e forest blocks). Statistical rules also support this concept (Cochran 1976). The spectral characteristics of any set of objects such as specific vegetation types or soil types are likely to vary over a large area. As variance increases, the likelihood of confusion between spectrally similar objects also increases. The criteria selected for partitioning the study area should therefore be physically significant and directly related to the variability of the surface types to be classified.

5.5.2 DIGITIZING TECHNIQUE

The input data used in this study were taken from two different type of maps. District boundaries were obtained from the 1: 100 000 topographic maps, and different forest blocks boundaries were obtained from 1: 25 000 photo-interpretation type maps.

Since the Scottsdale district has administrative and forest blocks boundaries in polygonal form (a figure with many angles and sides), these were digitized for later conversion to a format which could be merged with the Landsat data. Extensive map preparation was required before digitizing. As the input maps were of different scales, a base map highlighting various boundaries was traced from 1: 100 000 topographic map sheets of the study area. Since district and forest block boundaries follow rivers, streams and main roads, these were identified and traced from the topographic maps. The forest block boundaries were then digitized from the resultant overlay map (see Figure 5.4) and registered to the Landsat data using a map transformation technique available in the BRIAN software. The details of the BRIAN system is discussed in the next section.

The digitizing was performed using a Summagraphic Digitising System which is attached to a PDP 11/34 mini computer at CSIRO Division of Water Resources Research. This device features a large digitizing table with a free floating cursor. The Summagraphic digitizer uses a co-ordinate grid with units of 0.1 mm relative to an origin defined by the user at the start of the digitizing session. All points are recorded in these units as a distance from the origin along the horizontal and vertical axes to give X and Y co-ordinates respectively.

To relate these digitizer co-ordinates to image co-ordinates, ground control points must be selected and digitized. The map co-ordinates assigned to these control points must follow the same system (in our case Universal Transverse Mercator co-

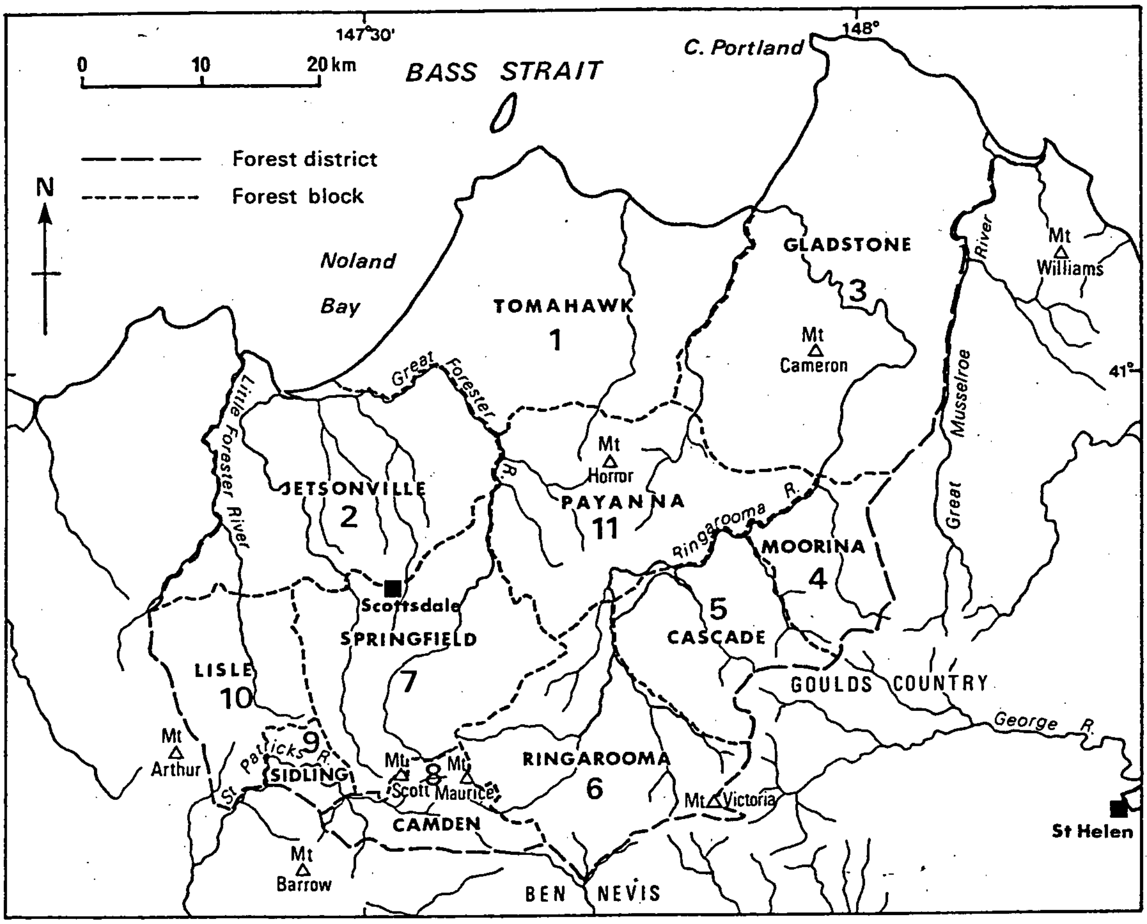


Figure 5.4 : Forest blocks within the Scottsdale District.

ordinates) as those used for control points in the image rectification procedure. For further details on GCP selection see Appendix A3.5.

In this project, the co-ordinates of the points on the map were entered as digitizer co-ordinates and the image co-ordinates were entered interactively using the BRIAN system.

So for the same point a, we can have

$$\begin{aligned} &DXa\ ,\ DYa \text{ -- Digitizer co-ordinates} \\ \text{and} \\ &IXa\ ,\ IYa \text{ -- Image co-ordinates} \end{aligned} \tag{5.1}$$

Given these two types of co-ordinates we need to determine the transformation f (x,y) and g (x,y) such that

$$\begin{aligned} &IXa = f\,(DXa\ ,\ DYa\ ) \\ \text{and} \\ &IYa = g\,(DXa\ ,\ DYa\ ) \end{aligned} \tag{5.2}$$

A set of 62 ground control points were selected and used to derive the required transformation using the BARRY programs of the BRIAN system. These transformations were then used to convert the district and forest blocks boundary points from digitizer co-ordinates to image co-ordinates.

To relate data in forest blocks to the pixels of a Landsat image, an algorithm was used to create a raster data plane in which the pixels inside each forest block, as well as pixels comprising the borders, were uniquely identified. This new attribute of each pixel, the number of the forest block it belongs to, becomes the key to merging the two forms of data.

5.6 THE IMAGE PROCESSING SYSTEM USED

The basic components of a digital image analysis system typically consist of a standard computer, tape drives, disk, terminals, an image display system and a device to provide hard copy image output. Certain special accessories can also be incorporated to facilitate the ease and efficiency of image analysis. In this project, the mini-computer based BRIAN (Jupp et al., 1985, 1986) and personal computer based microBRIAN (Micro Processor Applications, 1986) image processing systems located at the CSIRO Division of Water Resources Research, Canberra, Australia were used for the entire data analysis.

The mini-computer based processing system at CSIRO consists of a Hewlett Packard HP 1000/45 which is dedicated to image processing and based on the BRIAN software package. The system incorporates 170 Mb of disk storage, two tape drives, a graphics printer and a number of terminals. In this system, images are displayed via Ramtek colour display units and the results of the image analysis are printed using an Applicon inkjet plotter.

Digital data from a computer compatible tape (CCT) are read by the HP system and are displayed and manipulated on the colour monitor. User commands are entered via either a terminal keyboard connected to the computer, or a joystick style cursor control unit, which interacts directly with the colour monitor.

The microBRIAN is an advanced version of the HP mini-computer based BRIAN system. It contains the features of an advanced image processing system and algorithms for a wide range of general remote sensing and raster coded data analysis applications. The hardware and software environment for the microBRIAN structure and algorithm set is an integrated system which is board and bus compatible with an IBM PC XT/AT micro-computer having 640 K memory and 40 Mbyte of hard disk space, the Vectrix VX/PC Board and monitor system for graphics, the PC DOS operating system and Microsoft Fortran 77, C and assembler languages. For hard copy, the system uses an ink jet plotter and has screen dump and file based plotting algorithms to record the results of processing. The system is also expandable with options including image digitizer, high quality printers, a standard half inch 1600 BPI tape drive and a 80 Mbyte hard disk. (Jupp et al. 1986).

microBRIAN is organized as an hierarchy with four levels (see Appendix A4.0). Levels one and two are organizational and contain the bulk of the internal documentation associated with help. Level three contains the actual image processing programs. Level four of the overall hierarchy underlies the whole system and consists of utility libraries and subroutines which are used by most programs. (For further details see Micro Processor Applications, 1987).

5.7 LANDSAT IMAGE CLASSIFICATION AND DATA EXTRACTION TECHNIQUES

As mentioned earlier, digital analysis of Landsat data has successfully been used, especially in areas of low relief, to distinguish various Level I and Level II land use/cover types

However, in high relief areas, success have been limited. This is mainly because of complications in the radiance recorded by the satellite sensors.

In the following sections, the nature of the problems involved and the underlying factors are discussed in detail. Moreover, various techniques applied in classifying land cover classes in mountainous areas are examined.

5.7.1 FACTORS AFFECTING THE RADIANCE RECORDED BY THE SATELLITE SENSORS

There are many factors which cause variation in satellite recorded spectral data. These factors include the illumination conditions, site environmental conditions, reflective and emissive properties of various objects on earth, atmospheric conditions and satellite system related problems. In a high relief area, among all the above terrain variability factors, the illumination condition is the most critical. Understanding these factors is important in order to accurately classify the remotely sensed data.

Remote sensing by imaging sensors, like those of the Landsat system, record radiation reaching the sensors from a number of sources. Under clear atmospheric conditions, when remote sensing of land features is possible, the major component of the upwelling radiance comes from the land surface.

The source of the radiation which is reflected is the solar irradiance. The solar irradiance has both a direct component, consisting of unscattered sunlight and a diffuse component, consisting of light scattered by the atmosphere and surrounding terrain.

At the earth's surface, some of the irradiance is absorbed, heating the earth or providing the energy for photosynthesis and some is reflected to provide the signal sensed at the satellite. From most surfaces, the radiation is reflected in many directions. If the reflected radiation is distributed uniformly, the land surface is called a "Lambertian" reflector. Very few real land surfaces behave in a Lambertian way, but it is a commonly used model.

When the land surface is sloping, the reflected radiance is a function of irradiance, land surface type, and surface slope and aspect. The geometry of this situation is shown in Figure 5.5, where, Z is the solar zenith angle, a the azimuth angle of the sun from south, a' is the azimuth angle of the normal to the vertical surface from south, i is the angle between the sloping surface and a horizontal surface and Z' is the angle between the incident solar rays and the perpendicular to the sloping surface.

In a mountainous region, there are three factors which cause variation in satellite recorded data. These include reflected direct irradiance, reflected diffuse irradiance and path radiance. These factors are discussed below:

5.7.1.1 REFLECTED DIRECT IRRADIANCE

Reflected direct beam radiation constitutes the major part of the radiation received at the sensors and is most influenced by the topographic effect. This radiation is a function of the

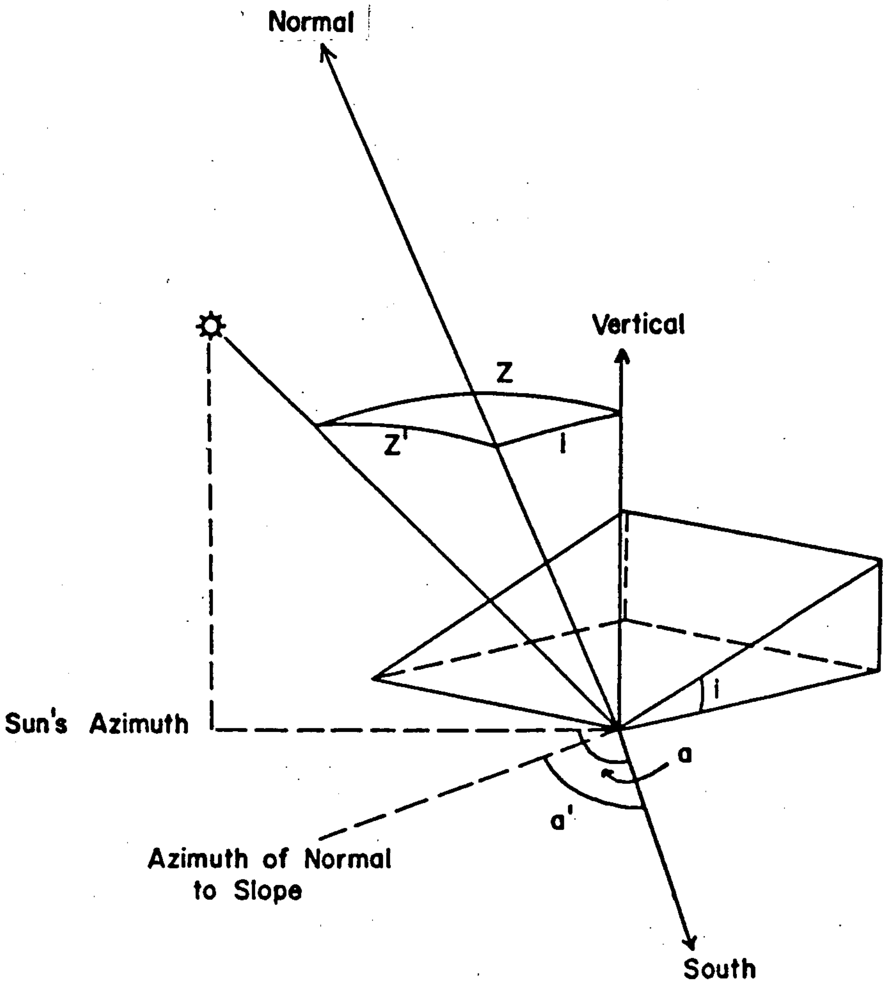


Figure 5.5 : Relation of the solar zenith angle to the energy incident on a sloping surface. (Adopted from sellers, 1965).

optical properties of the surface, the angle between the normal to the surface and the angle of incidence, and the angle between the normal to surface and the sensor.

Since the time required to record a single Landsat scene is small, therefore, in flat areas the illumination angle is constant for all pixels in the scene. However, in mountainous areas, the illumination angle varies significantly from one pixel to other, affecting the magnitude of the incident irradiance and radiance received at the sensor. This variation has also been reported by Hoffer et al. 1975 and Anuta 1976, as the major topographic effect.

5.7.1.2 REFLECTED DIFFUSE IRRADIANCE

The reflected diffuse irradiance received at a surface is composed of radiation both scattered and backscattered by the atmosphere and reflected by surrounding terrain. Incident diffuse irradiance is inherently multidirectional. For further details see Coulson (1971), Swain and Davis (1978), and Gates (1980). Justice and Holben (1980) measured diffuse irradiance on surfaces tilted at a range of slopes and aspects and showed variation with solar elevation, local slope and aspect. They concluded that due to the short data acquisition time of a single Landsat image, solar elevation can be considered constant but variations due to slope angles and aspect must be recognized as components of the topographic effect. They also pointed out that the contribution to the diffuse component due to reflection from surrounding terrain has received very little attention because of its measurement problems. Smith et al. (1980) measured the fraction of diffuse irradiance to the total irradiance during a Landsat overpass as less than 12 percent in all 4 MSS bands. Justice and Holben (1980) pointed out that in extreme cases, the variation in measured Landsat radiance related to the diffuse component was at most only three digital radiance numbers.

5.7.1.3 PATH RADIANCE

The path radiance is composed of two components. One component is the extraneous radiance scattered into the sensor from the atmosphere. The second component is reflected radiance that is subsequently scattered into the sensor. These components are generally small in magnitude and have been considered additive noise terms because they are related to the general scene reflectance rather than the reflectance of specific pixels.

5.7.2 EXISTING TECHNIQUES FOR REDUCING THE TOPOGRAPHIC EFFECT IN REMOTELY SENSED DATA

Unfortunately, topographic effects have received very little attention in the development of computer-aided land use/cover classification techniques. The techniques used up until the present can be categorized as:

1. preprocessing the raw data such as by band ratioing and
2. applying Lambertian, modified Lambertian and non-Lambertian reflectance models

The description and the logic behind the use of these are discussed below:

5.7.2.1 BAND RATIOING

This is a commonly used preprocessing technique to reduce the topographic effect in remotely sensed data. Ratioing can be defined as a division of one spectral band radiance value by the radiance value of another spectral band. Kriegler _et al_. (1969) and Maxwell (1976) discussed the main rationale behind its use and suggested that the use of ratios enhances inherent surface information because the illumination variations influence proximate wavebands proportionately and cancel out during the ratioing process. Kriegler _et al_. (1976) applied the ratioing technique to eliminate environmental effects which are considered multiplicative in nature. He reported the factors causing variation in radiance received on board satellite sensors as:

$$R_s = \underbrace{R_d(i,t)\,R_t(i,t)\,R_a(i,t)}_{\text{multiplicative term}} + \underbrace{R_b(i,t)}_{\text{additive term}} \quad \ldots\ldots(5.3)$$

where

R_s = Spectral radiance received at the sensor

R_d = Direct spectral irradiance impinging the target at time "t"

R_t = Target reflectance at time "t"

R_a = Atmospheric transmittance at time "t"

R_b = Scattered radiation by the atmosphere to the sensors field of view at time "t"

i = Angular parameters

The multiplicative term is direct irradiance attenuated by a quantifiable multiplicative transmission factors and as such is quantitative information, whilst the additive term is noise. The addition of the two form the total radiance. Kriengler et al. (1973), Crane (1971), Vincent (1973), Goodenough and Shlien (1974) and Goodenough (1979) all used ratioing in order to reduce multiplicative effects within multispectral data. Holben and Justice (1981) concluded that band ratioing reduced the topographic effect on their data by an average of 83 percent but did not eliminate it entirely. They concluded that unexplained residual effects were probably related to scattering from surrounding terrain and path radiance.

5.7.2.2 THE LAMBERTIAN AND NON LAMBERTIAN REFLECTANCE MODELS

The Lambertian model is based on the assumption that the solar radiation impinging on a surface is Lambertian, which is characterized by equal radiance scatter in all directions. Justice and Holben (1980) pointed out that the radiance from a surface can be modelled by the cosine of the incidence angle between the surface normal and the solar beam (Robinson, 1965). The radiance from a Lambertian surface, smaller than the instantaneous field of view of the sensor is

$$R = R_n \ (\cos i)$$

where

R = Radiance

R_n = Radiance viewed in a direction perpendicular to the target

i = Angle between the upwelling radiance and the normal to the surface

On the other hand if the surface is much larger than the

Instantaneous Field of View (IFOV) of the sensor, then the radiance R is independent of viewing angle. Holben and Justice (1980) analyzed the relationship between the radiance data received with the Lambertian model and radiance data received by ground based sensors. They reported a high correlation between the two data sets. Driscoll (1974), Cicone et al. (1977), Malila et al. (1977), Hoffer et al. (1979), Strahler (1979) and Smith et al. (1980) used a Lambertian model to correct Landsat data for topographic effects.

Some researchers, recognizing the underlying variations in the natural surfaces, applied modified or non-Lambertian models. For example Smith (1980) concluded that the Lambertian assumption is more appropriate for low slopes. In the case of high relief areas, sun, surface and sensor geometry changes and variation in the reflectance of individual cover type, result in variable sensor measurements for different pixels of the same cover type. Cicone et al. (1977) used a modified incidence angle based on a synthetic slope angle. In turn the synthetic slope angle was obtained by multiplying the actual slope angle by the sine of the solar zenith angle. The authors reported a marked improvement over the Lambertian model. Similar results were reported by Smith et al. (1981) when using a topographic correction technique developed by Minnaert (1941).

Other researchers Driscoll et al. (1971), Malila et al. (1978) Strahler et al. (1978) and Hoffer et al. (1979), included topographic data as added channels in feature space. In particular Malila et al. (1978) and Strahler et al. (1978)

developed various statistical probability distributions prior to classification, taking into consideration the topography and the targetted cover types.

5.7.3 SUMMARY

The classification process in high relief areas is more complicated due to the interactions of surface, atmospheric and sensor characteristics. Attempts to eliminate topographic effects rely on band ratios, multi-dimensional analyses which use topographic data as added dimensions and physical models which estimate the reflection of solar radiation from slopes.

5.8 LANDSAT IMAGE CLASSIFICATION USING LANDFORM INFORMATION AND ANCILLARY DATA

In this project, in response to the topographic problem, a radiance model was specified and log transformations, as well as ratios were applied to the raw Landsat data (Ahmad et al. 1986). The intent of this approach was to define classes on the basis of both spectral similarity and illumination, that is, sunlit versus shadowed. Figure 5.6 illustrates the analysis procedure which was applied to both the 1980 and 1984 images (Table 5.2). The following section provides details of the various steps followed and the mathematical model used. To illustrate the results at various stages of the analysis, a representative subset from the 1984 image was used (see Figure 5.3). This particular area was chosen because it included most of the land cover and relief types found in the Scottsdale district.

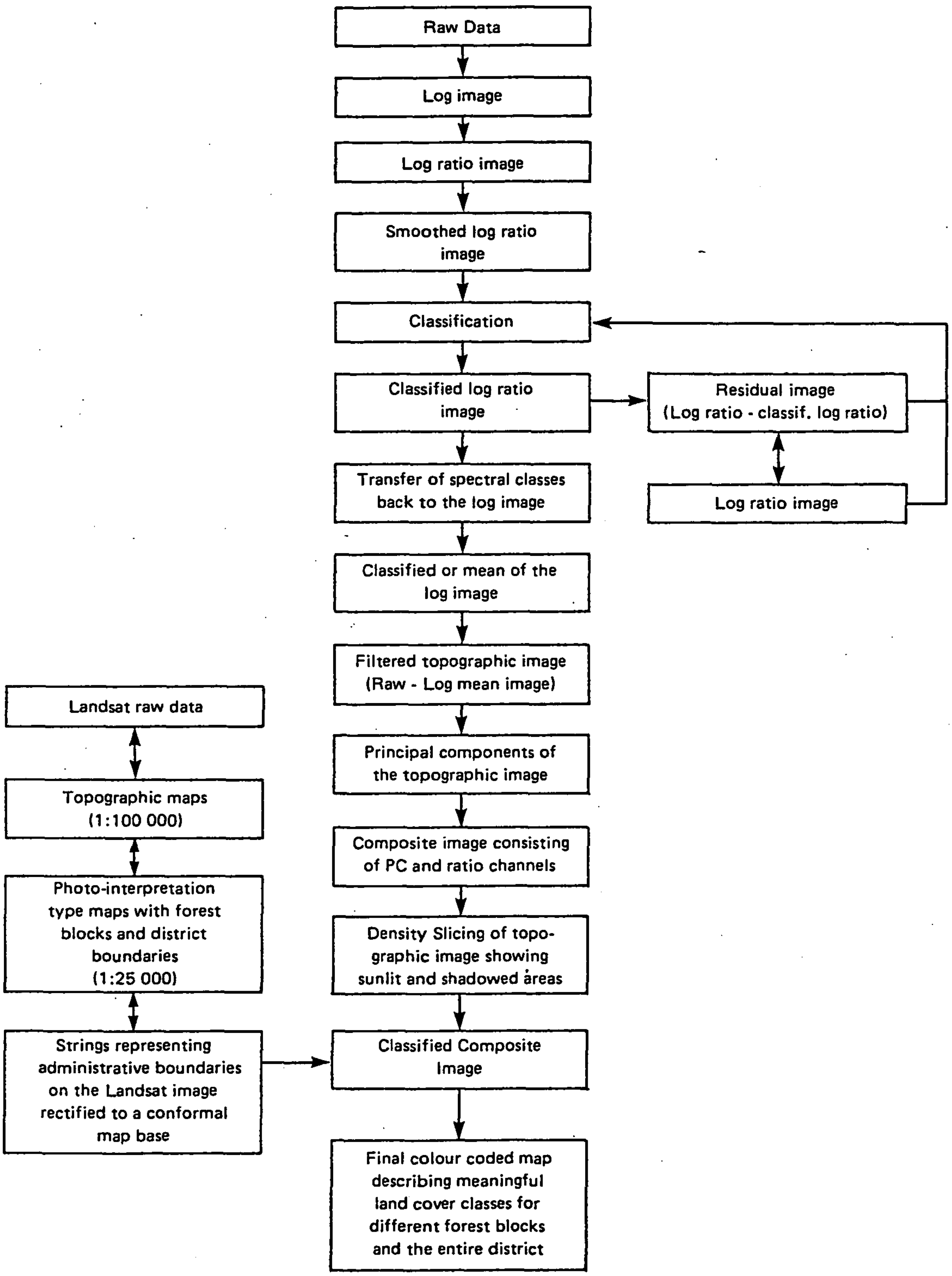


Figure 5.6 : Flow diagram of the analysis procedure followed in the project.

5.8.1 BASIC UNDERLYING MODEL

Consider a Landsat scene encompassed by N pixels (i = 1 to N), nb bands (j = 1 to nb) and nc values of land cover (k = 1 to nc). In terms of land cover, the total number of pixels in the scene (N) can be described as

$$N = \sum_{k=1}^{n_c} Q_k \qquad (5.4)$$

where Q_k denotes the number of pixels in the scene which fall under land cover category k. Using this labelling convention, the satellite recorded radiance in pixel i, channel (or band) j and land cover type k (Y_{ijk}) has the following form:

$$Y_{ijk} = T_j \; r_{jk} \; G_j \; c_{ij} + d_j \; u_i \qquad (5.5)$$

where

- T_j is atmospheric transmission in band j
- r_{jk} is reflectance in band j for cover type k
- G_j is irradiance in band j on a horizontal surface
- c_{ij} is the topographic modulation factor
- d_j is atmospheric path radiance, and
- u_i is potentially an atmospheric inhomogeneity term (independent of wavelength)

The topographic modulation factor, c_{ij} , is 1.0 for a flat surface and less than or greater than one for slopes away from and towards the sun respectively. For Lambertian surfaces (uniformly diffuse reflected radiance) and low or no diffuse incident radiation, c_{ij} takes the following form:

$$c_{ij} = \text{maximum } [\cos(Z')/\cos(Z), 0] \qquad (5.6)$$

where

Z is the zenith angle of the sun

Z′ is the angle between the sun vector and the normal to the slope

More generally, c_{ij} can be defined as the a modification of G_j such that:

$$G_j\ c_{ij} = a_i\ S_j + b_i\ D_j \qquad (5.7)$$

where a_i and b_i depend on the local slope and aspect and S_j and D_j are the band specific direct and diffuse irradiance terms such that $G_j = S_j + D_j$. That is

$$c_{ij} = a_i + (b_i - a_i)\ [D_j/G_j] \qquad (5.8)$$

If we assume that $[D_j/G_j]$ is small or constant for the bands being used, the dependence of c_{ij} on j disappears and the model may be reduced to:

$$Y_{ijk} = c_i\ X_{jk} + d_j\ U_i \qquad (5.9)$$

where, X_{jk} is the composite term $[T_j\ G_j\ r_{jk}]$.
When the atmospheric inhomogeneity term is negligible, then $d_j\ U_i$ could be replaced by d_j. If the land cover is uniform, the model reduces further to:

$$Y_{ij} = c_i\ X_j + d_j \qquad (5.10)$$

This form is identical to the one used by Switzer et al. (1981) to estimate d_j by the covariance matrix method. (See

Appendix A3.3).

When the land cover is not uniform, the effect of slope (c_i) can be eliminated and an expression for r_{jk} can be obtained which gives land cover unaffected by shading. For the purposes of the image classification presented here, a fact exploited by Wang et al. (1984) was used. This involved obtaining a ratio R_{jlk} which is related to the radiance recorded from the same pixel but at different wavelength bands:

$$R_{jlk} = (Y_{ijk} - d_j)/(Y_{ilk} - d_l) \qquad (5.11)$$

In the absence of noise in the Y_{ijk} this ratio tends to equal to

$$\sim X_{jk}/X_{lk} \qquad (5.12)$$

The above expression, if the d_j were known, is independent of c_i and only a function of spectral cover type. In practice, the presence of noise and model inadequacy makes Equation 5.12, a useful approximation.

The method used therefore, was to estimate the d_j terms using Switzer et al., 1981 and Appendix A3.3 method and to form ratio images or rather the logarithm of the ratio images obtained from Equation 5.12. The log ratio images were then classified using the BRIAN image processing system. The classification procedure is discussed in detail in the following section.

Table 5.3 provides a stepwise summary of Landsat data extraction technique employed in the project and the products generated from the extracted information.

Table 5.3

Step-wise summary of Landsat image classification and data extraction technique using landform information and ancillary data

Technique applied	Programs used	Function	Output product
PREPROCESSING			
Study area definition on Landsat tapes	SBSET	To create 3 disk files (512 pixels by 1024 lines) by 4 bands from CCT'S which cover study area	Raw data image files and printed histograms for each band
Colour enhancement or stretching	JLAT	To enhance features of interest using various colour image enhancement techniques	Enhanced raw data image on display screen
	IJET	To produce hard copy output of enhanced images	Applicon inkjet plots of enhanced images
Destriping	PEEK	To eliminate striping from the raw data	Destriped image files
Manual and spectral digitising	DIGIT	To manually digitise out the unwanted areas from the image e.g ocean area	Digitised image files
	SPDIG	To spectrally scissor out unwanted area by using spectral themes e.g cloud effected areas	Spectrally digitised image files
CLASSIFICATION			
Log image	LOGTR	To apply log transformation to each band and of preprocessed image	Log image files
Log ratio image	AFFTR	Use affine transformation to transform log images to log ratio images (bands 4 to 7 being replaced with 4/5, 6/5, 7/5, 7/6 band ratio respectively	Log ratio image files
Smoothed log ratio image	SMOOO	Uses a 3x3 smoothing filter over images to emove random noise. Each pixel values are replaced by the smoothed values	Smoothed image files
Training areas selection from log ratio image	TRAIN	To get variance-covariance matrix and to determine the significant correlation of various ratios used	Printed matrix
		To get histograms of log ratio image	Printed histograms for each band of each image
		To cross plot the most significant ratio bands. In this project band ratio 4/5 (x-axis) cross plotted against 7/5 (y-axis)	Printed cross plot showing the distribution bution of spectral data in two dimensions
		To determine seeds values of themes derived from histograms and cross plot	File of seed values and printed theme statistics
Classifying log ratio image	CLASS	To classify images using seed values	Classified image file and classification statistics
		To determine if and where additional training areas are required. This is determined by viewing classified and residual images	Applicon inkjet plots of the classified and residual image
Transfer of spectral classes	SPTRN	To spectrally transform the classes generated in the classification process back to log image and to generate a classified log image	Classified image files and transferred classification statistics
Difference or filtered topographic image	DIFIM	To subtract the classified log ratio image from the log image i.e Log - Classified log ratio image = Residual or topographic image	Topographic image files

Table 5.3 (cont.)

Principal component image	PCATR	To get the variance-covariance matrix of the filtered topographic image	Printed matrix
		To obtain the PCA transformation matrix of the topographic image	Printed matrix
		To produce principal component image by using PCA matrix of the topographic image	PCA image file
Composite image	MULTI	To combine channels from different images In this project composite image consisted of 4/5, PC1, 7/5 and 7/6 respectively	Composite image files
Density sliced image	TRAIN	To find out brightness levels themes using PC1 channel	Printed themes
	OVRLY	To map out brightness levels	Overlayed image files
Classify composite image	CLASS	To classify composite image using seeds files which consisted of classes split according to their brightness levels splite sunlit and shadowed	Classified image files and clasification statistics
	CANVA	Canonical variates analysis to assess the level of split within and between the spectral classes	Printed analysis results
Spectral classes aggregation to meaningful land cover classes	TAXON	To obtain minimum spanning tree (MST) and dendograms for graphic analysis of spectral classes similarity	Printed MST
	COKUR & COTAX	To obtain MST of spatial similarity of spectral classes	Printed MST showing the spatial closeness of spectral classes
	OVRLY IJET	188 spectral classes aggregated to 28 detailed and 12 broad land cover classes using spectral and spatial MST'S	
Labelling for the final output map	OVRLY IJET	Assignment of meaningful labels to the aggregated classes using ancillary information such as field data, photo interpretation type maps, vegetation type maps and aerial photographs	Colour coded maps describing actual land cover classes for different forest blocks and for the entire district
Rectification	CNTRL	To locate ground control points (GCP'S) in images	File of image GCP co-ordinates
	GCPGN	To create and edit GCP'S file	File of map GCP co-ordinated
	NOMNL	To convert image and map GCP coordinates to a conformal co-ordinate base	Transformed GCP'S files
	SIEVE	To detect outliers GCP'S in files	Printed statistical summary showing spatial distribution of GCP'S and outlier points
	MODEL	To fit polynomial models between nominally transformed two GCP'S files	Transformation file and a printed summary of models used, their parameter and results
DATA INTEGRATION			
Integrating district and forest blocks boundaries with Landsat and digital terrain data	MAPEDIT	To digitise various lines representing district and forest blocks boundaries	
	MINTEG	To stratify the image by assigning a a unique number in one channel to pixels within each forest block. This enabled analysis of different forest blocks separately	An image file
	PASTE	To paste digitised boundaries onto the final classification map	Image file highlighting digitised boundaries

Table 5.3 (ctd.)

SUPER	To write classification and super (aggregated) class channel	An image file
MAPPR	To resample and mosaicing images to a common map base grid	Resampled and mosaiced image
MULTI	To create a new image by selecting channels from different images	A four channel image containing digitised boundaries, digital terrain data, classification and super class channel

5.8.2 CLASSIFICATION PROCEDURE

5.8.2.1 TRAINING SET SELECTION AND THE PROCESS OF SPECTRAL CLASS GENERATION

The concept of training set selection is to select sets of homogeneous pixels which are identifiable on the image and representative of different surface cover types. The interactive training algorithm used in the BRIAN system provides mean values of the grey level data from each image channel, and variance statistics such as standard deviation associated with each user defined training area. The quality of the training areas is judged by the standard deviation associated with each spectral band. In this study a standard deviation less than 2.5 was used as a criterion for accepting themes as representative of specific land cover types. Based upon the spectral responses selected from the small training area themes, the classifier then groups similar surface cover types on a pixel by pixel basis.

The classification algorithm used in the BRIAN system (Jupp et al., 1986) is a nearest neighbour classifier with optional class generation when the training sets are not exhaustive. In this classification, the computer scans the image and allocates each pixel (x) to its nearest spectral class (S_i) in the following measure:

$$\text{dist}(x, S_i) = \sum_j |X_j - m_{ij}| / \text{gate } j \qquad (5.13)$$

where:

X_j = represents the data in channel j of pixel X

S_i = Spectral class i

m_{ij} = the value in channel j of the mean for class i

gate j = tolerance level (proportional) to the within class standard deviation in channel j)

This is also subject to the condition that each spectral class considered must satisfy

$$L_{ij} <= X_j <= U_{ij} \qquad (5.14)$$

where

$L_{ij} = m_{ij}$ - gate j and

$U_{ij} = m_{ij}$ + gate j

Generally, the parameter gate j is chosen to be a multiple of the within class standard deviation for that band. When X_j does not fall between the lower and upper limits L_{ij} and U_{ij} for any of the classes, the pixel in question is not represented by any of the existing classes and either becomes a new class or is put in the unclassified category if new classes are not permitted.

The objective of this stage of the classification was to produce a set of spectral classes which represents all the variation in the image. The candidate training sets, therefore, were selected in a number of ways to achieve full coverage of the variation.

Various training set selection techniques can be employed using the above algorithm. Various techniques used in this study to obtain a training set selection are described below:

i) Supervised training area selection

Based on the information gathered during the ground reconnaissance survey, a number of training areas representative of known land cover types were selected from the smoothed log ratio image (Figure 5.7).(see Table 5.3).

ii) Visual pattern selection

Here, unknown, but apparently distinct land covers, showing as visible coloured patches on the image were selected as training sets in the same way as the known patterns.

iii) Unsupervised theme seeding

To ensure that the spectral variation in the image is sampled and incorporated in the classification procedure, a procedure was adopted to independently sample and enter themes based purely on two dimensional spectral histograms. In this case, the least correlated ratio channels 4/5 and 7/5 are key separators of the ratio data. Figure 5.8 shows a two dimensional spectral representation of band ratio 4/5 plotted against band ratio 7/5. The procedure consisted in defining boundaries formed by the 1 to 95 percentage values of the individual histograms for the 4/5 and 7/5 ratios (Figure 5.9). This procedure defined 36 boxes in Figure 5.8. The centre of the mass in each of the boxes was calculated by using the THEME program and the generated central values for these boxes were used as additional themes in the classification procedure.

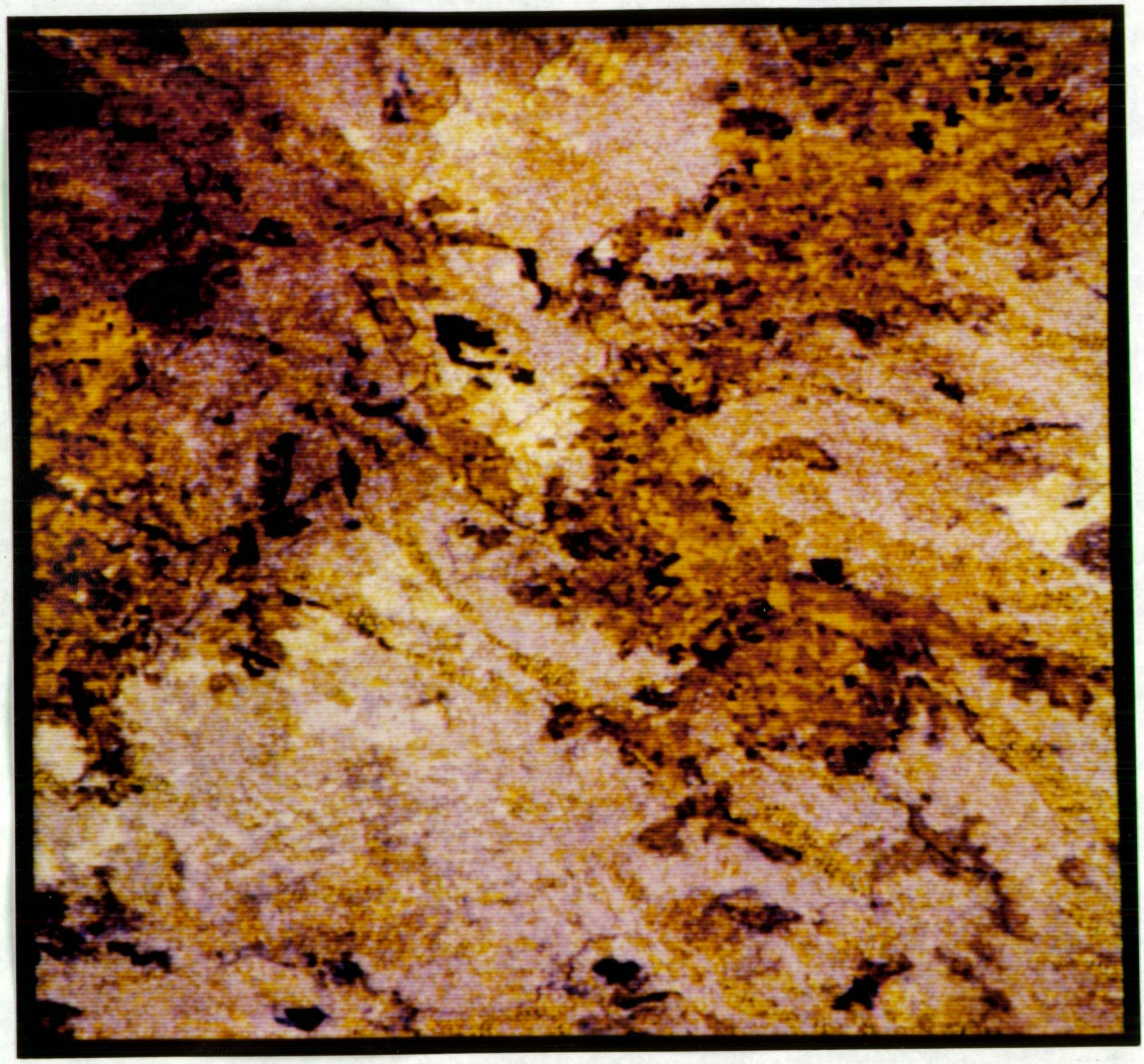


Figure 5.7 : Smoothed log ratio image for the representative study area

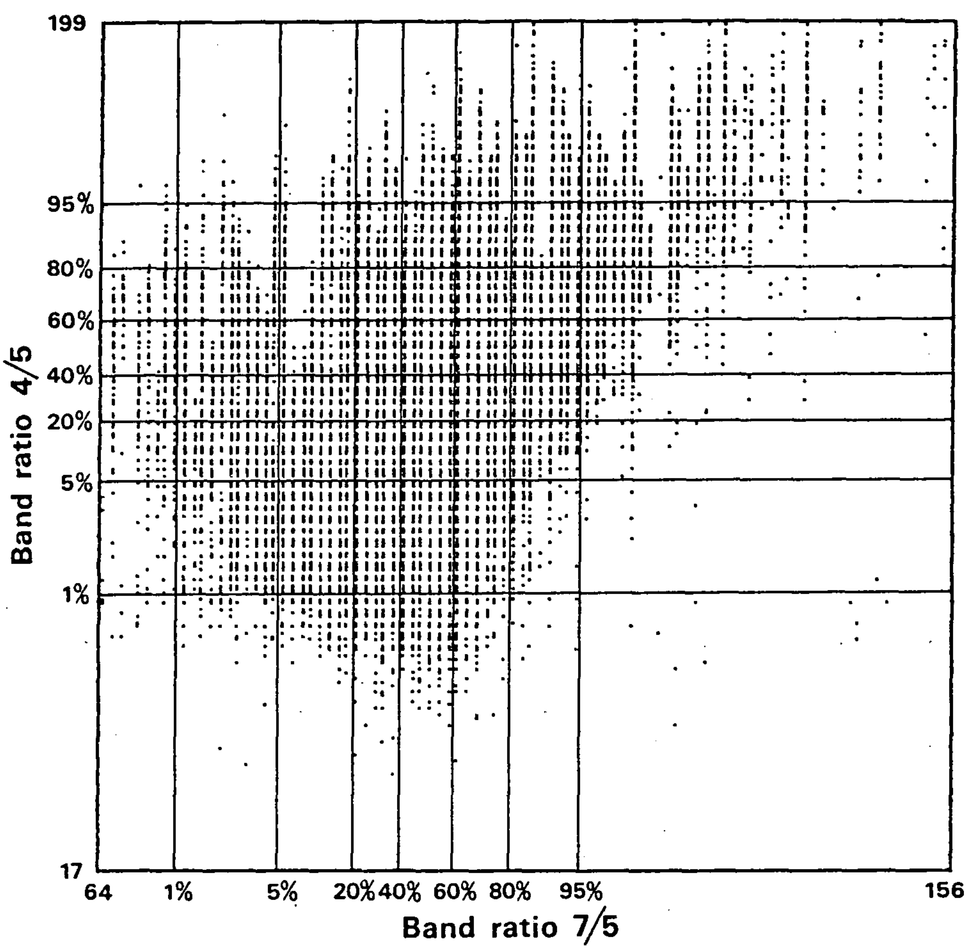
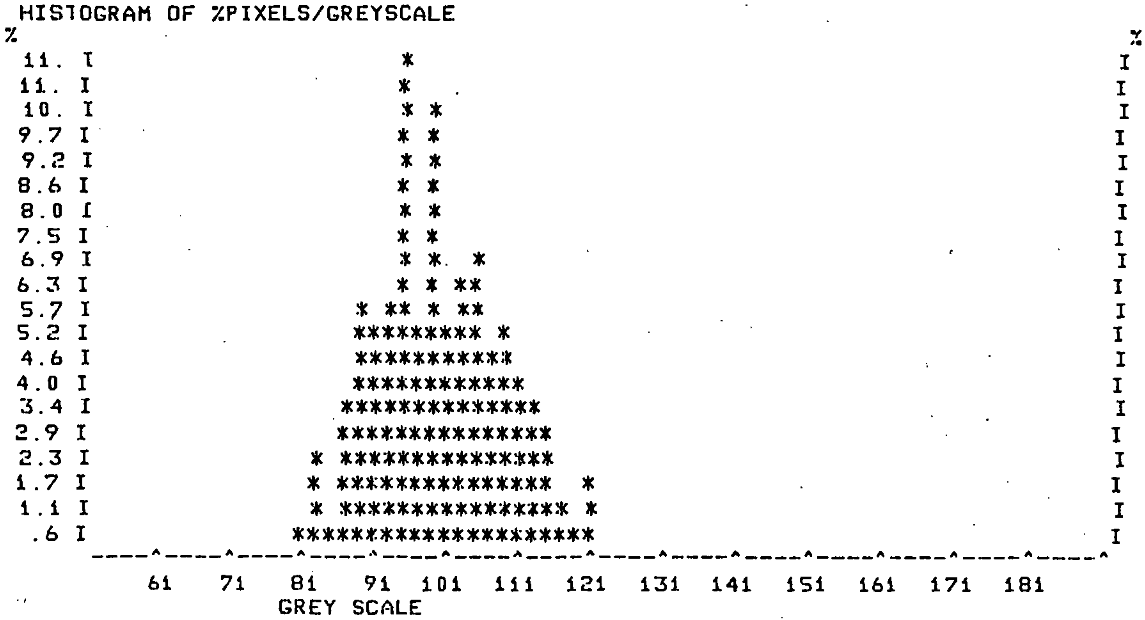


Figure 5.8 : Scatterplot of two band ratios, (band ratio 4/5 data range 64-156 and 7/5 data range 17-199).

(a)

```
Band  no. 4/5 maximum count on level  100 being   37319. pixels
Total of    511817. pixels.   min    0  max  200

Percentage points are -
     1%   5%  10%  20%  30%  40%  50%  60%  70%  80%  90%  95%  99%
     64   84   89   92   95   97   99  102  105  109  113  117  149
```



(b)

```
Band  no. 7/5 maximum count on level  122 being   17949. pixels
Total of    511817. pixels.   min   37  max  227

Percentage points are -
     1%   5%  10%  20%  30%  40%  50%  60%  70%  80%  90%  95%  99%
     59   99  106  113  118  123  128  135  141  146  154  159  199
```

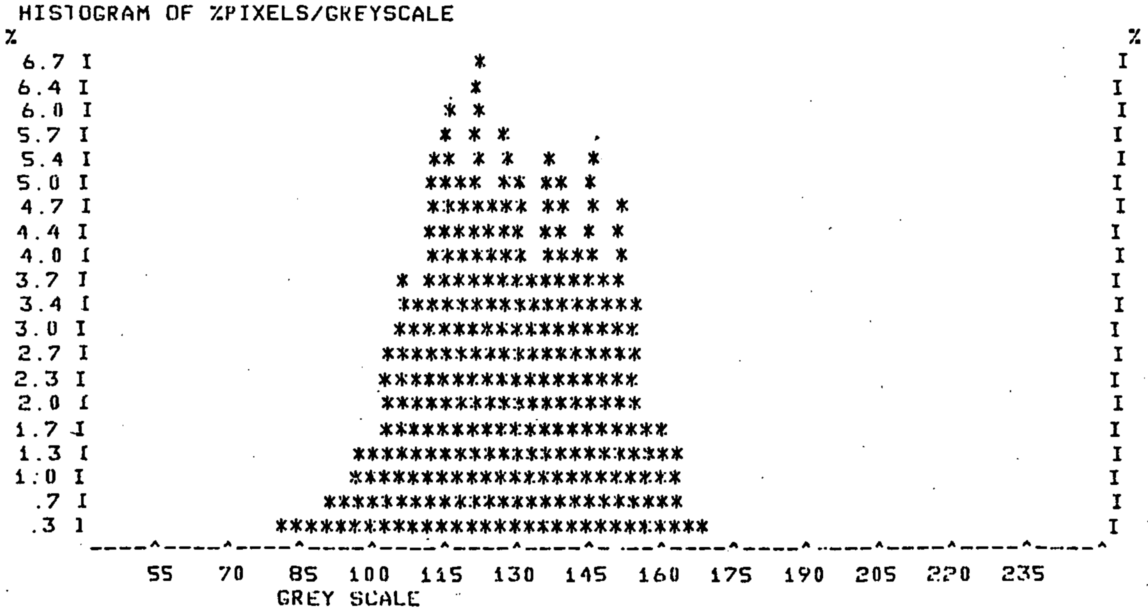


Figure 5.9 : Histogram of band ratios 4/5 (a) 7/5 (b)

iv) Residual image based training

As a result of the classification procedure, two types of images, a mean and a residual image, were produced. A mean image is one in which the spectral values of each pixel are replaced with the mean values of its assigned class. The residual image is the difference between the original raw data and the mean image. Spatial patterns or coherence in the residual image indicate regions where more training areas are necessary to fully exploit the spectral information. As reported in Jupp and Mayo (1982), the use of the residual image increases classification precision since it can produce a more refined set of spectral classes. This procedure was used which enabled to generate more training areas. The classification procedure was iterated until no significant pattern was apparent in the residual image.

Figure 5.10 represents the final classified image. The resultant residual image which was obtained after four iterations is shown in Figure 5.11.

The iterative procedure generated spectral classes of generally uniform land cover type. The next step was to extract the topographic (or shaded land form) component from the original raw data. This was accomplished by transferring the classes based on the log ratio image back to the logarithm of the data using the SPTRN program. This program imposes a classification mask derived from one image to another spatially conforming image.

From Equation 5.9, the logarithm of the radiance in

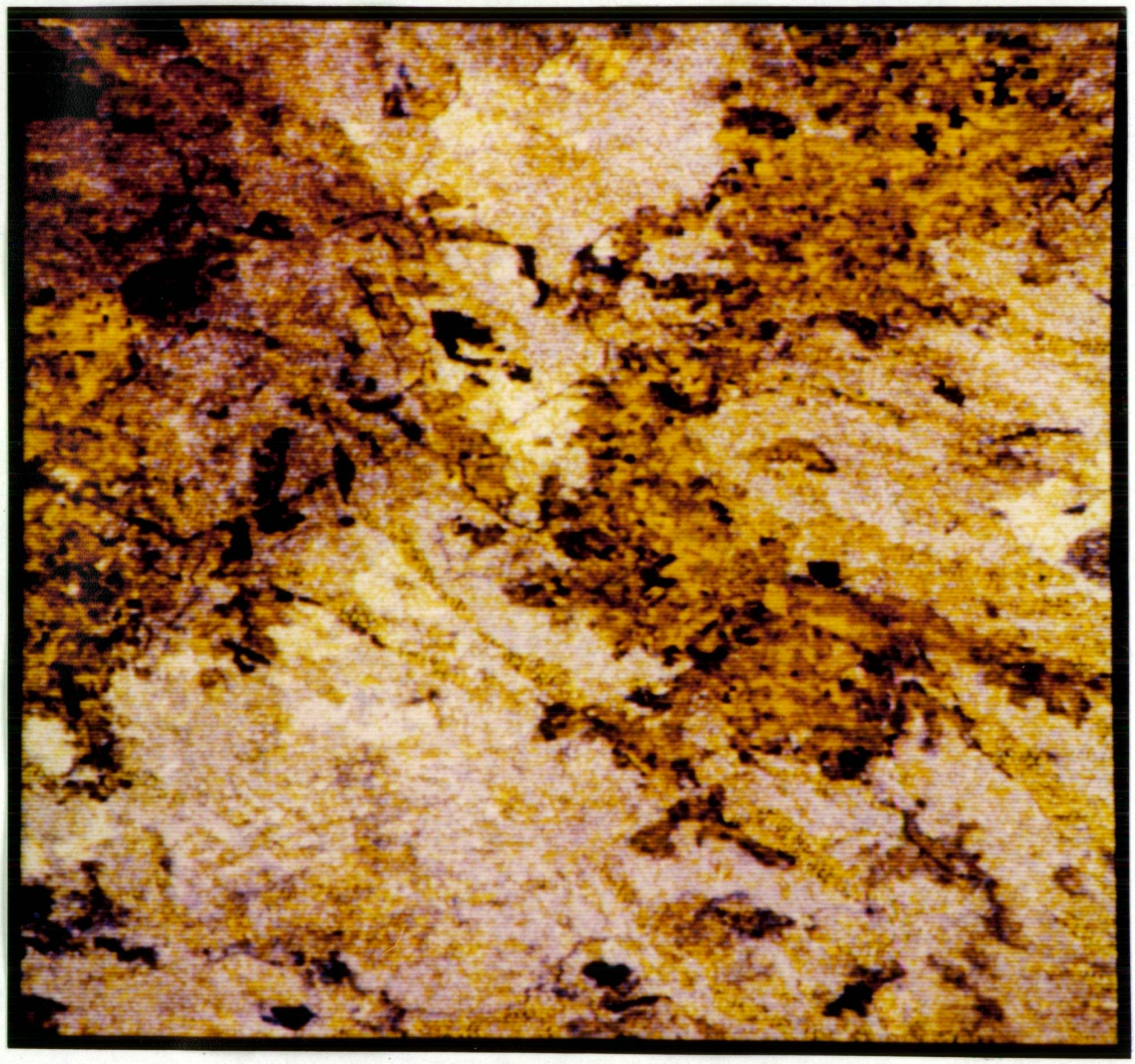


Figure 5.10 : Mean log ratio image for the representative study area.

Figure 5.11 : Residual image for the representative study area .

pixel i, band j and land cover k is :

$$L_{ijk} = \text{Log } (Y_{ijk} - d_j)$$

$$L_{ijk} = \text{Log } (c_i) + \text{Log } (X_{jk}) + u_{ij} \qquad (5.15)$$

Using SPTRN, it is possible to average L_{ijk} for all pixels contained in a class. This procedure result in the estimation of a mean pixel radiance $\bar{L}_{jk}$ for band j and land cover k :

$$\bar{L}_{jk} = \text{Log } (\bar{c}_k) + \text{Log } (X_{jk}) \qquad (5.16)$$

where $\bar{c}_k$ is a mean topographic modulation factor for class k.

SPTRN produces an image which is identical to the mean image of the classification except that the L_{jk} replace the means of the log ratio. The residual image between this new mean image and the L_{ijk} image therefore has the following form

$$\begin{aligned} E_{ijk} &= L_{ijk} - \bar{L}_{jk} \\ &= \text{Log } (c_i/\bar{c}_k) + u_{ij} \end{aligned} \qquad (5.17)$$

Here, u_{ij} represents random noise, and $\bar{L}_{jk}$ and $\bar{c}_k$ are mean values taken over the k'th ratio class. E_{ijk} has the form of a residual image (Jupp and Mayo, 1982), between the log data and a computer based classification of it, which is free of the illumination variation.

The residual image E_{ijk} described in Equation 5.17 has only one linear factor (landform), which is independent of channel j. The first principal component (PC1) of E_{ijk} described as P_{ik} (Figure 5.12) retrieves the relief and shading or

Figure 5.12 : PC1 of the residual image for the representative study area.

brightness information.

If we assume that a complete range of aspects to occur uniformly in land cover classes, $\bar{c}_k$ will be approximately equal to a common value $\bar{c}$. However, even when $\bar{c}_k$ varies, it is worth noting that the variance of P_{ik} is a function of relief and that within high relief classes the relatively sunlit and shaded areas can be thresholded using P_{ik}.

As a next step a composite image was formed by adding data from the first principal component P_{ik} to the logarithm of the band ratios 4/5, 7/5, and 7/6. Using P_{ik} a density sliced image was then created representing sunlit and shaded areas. Each class was then subdivided according to its brightness level by replacing the P_{ik} values. The composite image was then reclassified using the minimum distance algorithm described in Equation 8. This procedure resulted in 168 and 188 spectral classes for the 1980 and 1984 scenes respectively.

5.8.2.2 STATISTICAL ANALYSIS OF THE CLASSIFICATION

An analysis of the separability between spectral classes generated above was obtained by using analytical techniques provided by the BRIAN software. These techniques included Canonical Variates Analysis (Hope, 1968) and Minimum Spanning Tree or MST (Gower and Ross, 1969)

Canonical variates analysis measures the separability of clusters and analyses the results of a classification as measured by the ratio of between group variance to within group variance. An uncorrelated linear transformation of the spectral bands is produced that has greatest amount of separability in the first channel (or band) and lesser amounts in the succeeding channels. That is, the first canonical variate accounts for the greatest ratio of between class variance to within class variance of all linear combinations of the spectral bands. The second canonical variate accounts for greatest variance ratio among components which are independent of the first, and so on with the remaining components. A plot of class means in the dimensions of their first two canonical variates yields a plot which maximally displays the spectral separation between the classes of all two-way cross plots of the means (Hope, 1968).

The patterns and gradients within the canonical variate plots, or band cross plots can be delineated using the Minimum Spanning Tree (MST). The MST is a graph which spans the set of classes joined together with straight lines such that no closed loop occurs. Classes linked on the tree are near neighbours spectrally and the tree has the property that it has minimal total length. For further useful properties of MST see Zahn (1971) and Webster (1977).

Canonical variate plots of the 168 and 188 spectral class means of the two classified Landsat scenes, together with their associated Minimum Spanning Tree are illustrated in Figures 5.13 and 5.14.

5.8.2.3 SPECTRAL-SPATIAL CLASSES AGGREGATION

Generally, the classification procedure produces a large number of tightly defined classes, so these classes must be

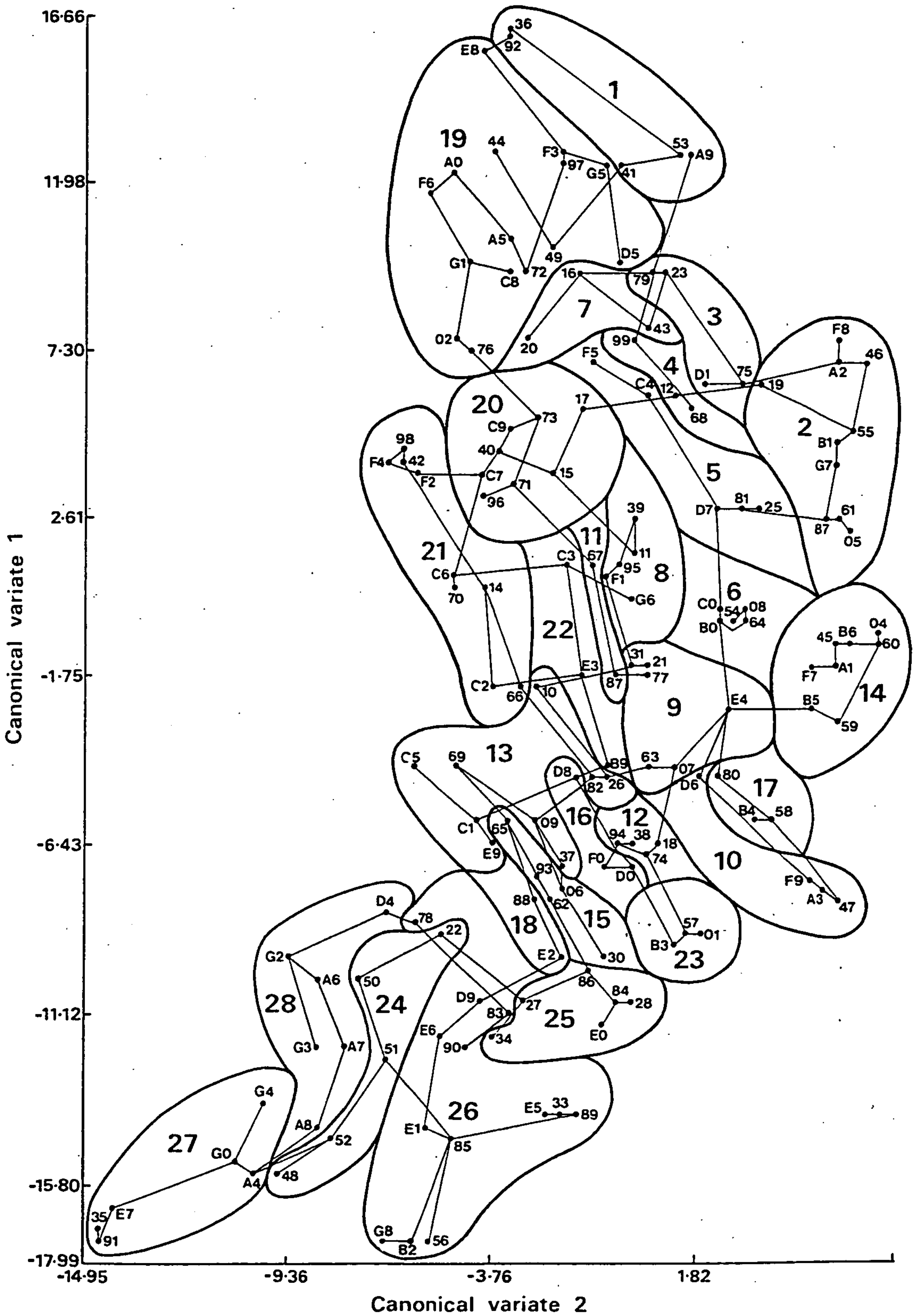


Figure 5.13 : Canonical variates plot: 28 Land cover types (1980) .

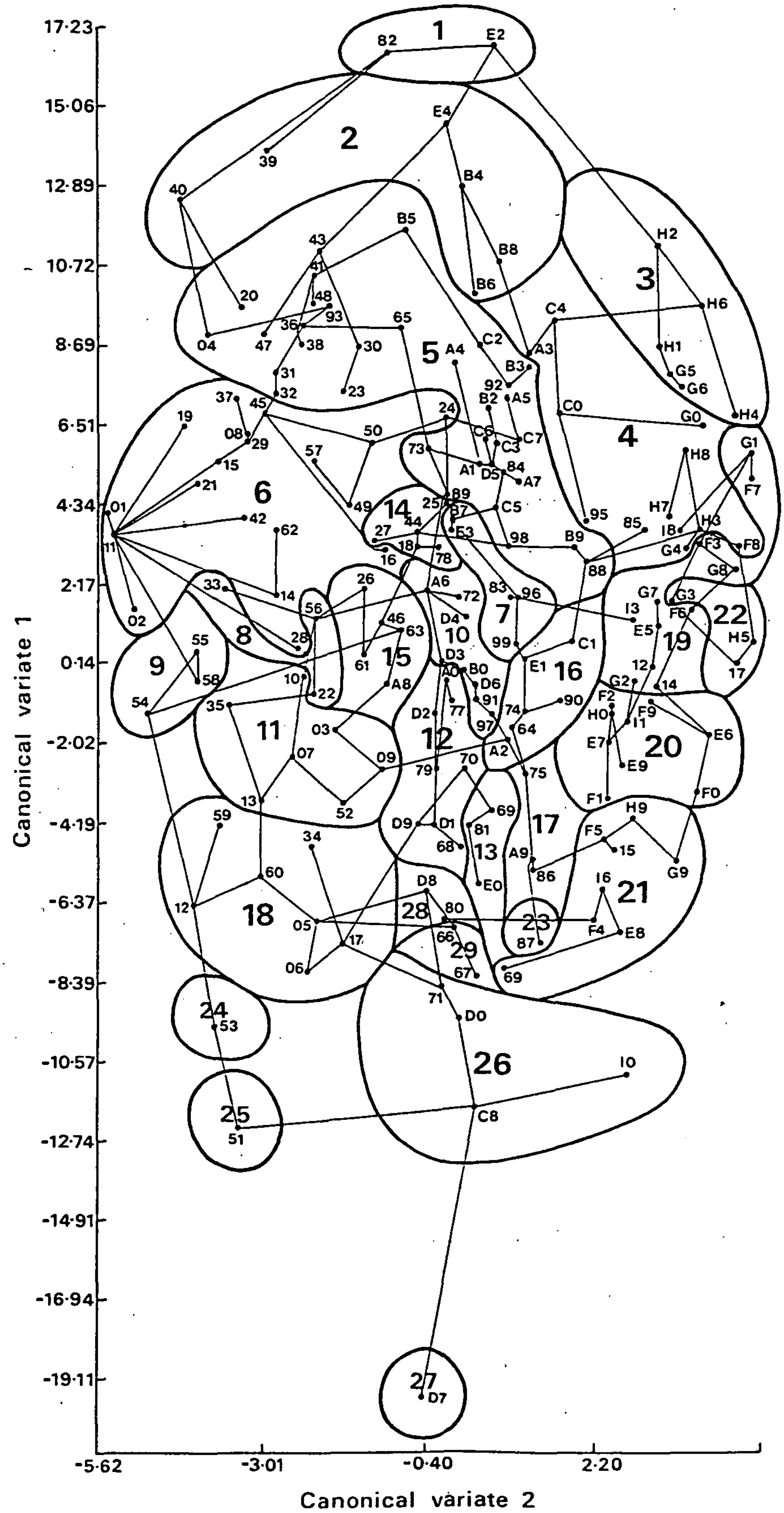


Figure 5.14 : Canonical variates plot: 29 Land cover types (1984)

reduced to a number which adequately reflect the full range of variation within the image data without excessive subdivision. This is done in two phases. In the first phase, some of the spectrally similar classes are merged. This was performed by evaluating the Mahalanobis Distance D^2 value of the generated 168 and 188 spectral classes for 1980 and 1984 respectively. This technique calculates the difference between the mid-point values of the original themes and the mean values of the pixels assigned to each of the themes weighted by the within class inverse covariance matrix. Classes with low D^2 value (That is less than 1) are merged together.

The second phase involves the aggregation of classes that are spatially contiguous as well as spectrally similar. This is the final editing phase of the classification where the number of spectral classes is reduced to a smaller number of meaningful land cover classes. This can be achieved either by displaying the spectral classes on the colour monitor and assessing their spatial patterns visually, or by analyzing the spatial similarity of classes using their co-occurrence statistics (Cliff and ord, 1973). These statistics provide an estimate of spatial autocorrelation in a classified image. As a measure of the frequency of co-ocurrence between classes it describes features of the spatial pattern in the image.

In this study, using spatial and spectral minimum spanning trees, contiguity of the 168 and 188 spectral classes was established by interactive viewing of the classes on the screen. Spectral classes were only aggregated if they were spectrally similar and intermixed spatially when displayed on the screen. That is, the classes show contiguity to a point where, as an aggregated class, they form a much more spatially compact class than they would separately. Where spectrally similar classes were spatially different, those classes were kept separate. Such editing assumes an interdependence between spatial and spectral information, and avoids aggregation based on spectral values alone, since similarity measures based on the attributes of the individual pixels are rarely able to retain this subtle interdependence (Jupp et al., 1986).

5.8.2.4 LABELLING OF SPECTRAL CLASSES

In order to assign a meaningful label, each spectral class from the classified image was overlaid on the image and a label was assigned. To test the consistency and representative nature of the label, spectral classes were mapped onto the three subsets covering the entire study area. In some cases aggregation of the spectral classes discussed in section 5.8.2.3 was reassessed by looking at the spatial distribution of the spectral classes in the entire study area.

The interpretation of the spectral classes in each of the forest blocks and the Scottsdale district as a whole was performed with the help of existing vegetation type maps, photo-interpretation maps prepared by the Tasmanian Forestry Commission and in consultation with field staff and researchers who had a detailed knowledge of the study area. In the case of the 1980 Landsat scene, 168 spectral classes were aggregated to form a map of 28 different land cover classes (Figure 5.15). The 188

Figure 5.15 : Classified Landsat image of the study area showing 28 land cover classes - 1980
(For colour codes see Table 5.4).

spectral classes generated during the classification of 1984 Landsat scene produced a map of 29 land cover classes (Figure 5.16). In both classified scenes, the same land cover types were identified and mapped with the exception of the additional class "Dieback" in the 1984 image, which was concentrated mainly along the northern coastal area. This land cover could not be mapped in the 1980 image because of missing data due to different scene centres in the Landsat 2 and Landsat 5 images.

It should be noticed that the aggregation of spectral classes depends on the objectives of the study. Scientists and managers with different requirements may assemble different interpretations from the same basic set of spectral classes. In this project, 28 land cover classes in the 1980 Landsat image were further aggregated to form a land cover map of the district with 11 broad classes (Figure 5.17). In the case of the 1984 Landsat image, 29 land cover classes were aggregated to 12 broad classes (Figure 5.18). Details of these classes are given in Tables 5.4 and 5.5.

5.9 ACCURACY OF LANDSAT DATA BASED CLASSIFICATION

5.9.1 IMPORTANCE OF ACCURACY ESTIMATION

The last step in the classification procedure is to determine its accuracy. As a map is always a generalization of the environment and never a true representation, methods are needed to estimate to what extent generated maps resemble the landscape they describe. For this purpose, comparisons between ground truth data and map data, as well as statistical analyses of field

Figure 5.16 : Classified Landsat image of the study area showing 29 land cover classes - 1984
(For colour codes see Table 5.4).

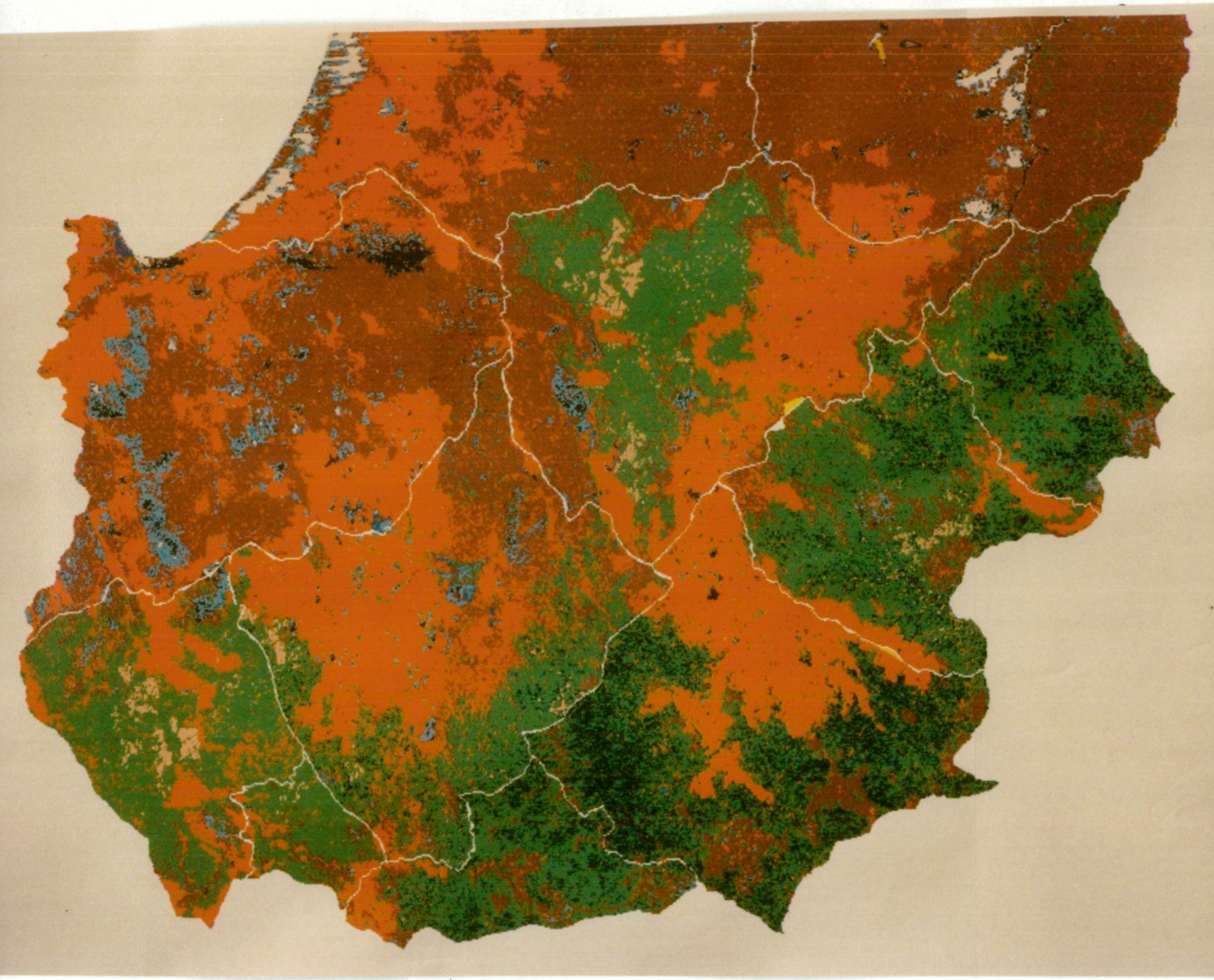


Figure 5.17 : Classified Landsat image of the study area showing 11 land cover classes - 1980
(For colour codes see Table 5.5).

Figure 5.18 : Classified Landsat image of the study area showing 12 land cover classes - 1984
(For colour codes see Table 5.5).

Table 5.4

Description of 29 land cover classes mapped in Scottsdale District, north east Tasmania, Australia

Pine plantation

Rainforest

Mixed forest (eucalyptus with dense rainforest understorey)

Wet sclerophyll forest (oldgrowth with regrowth and a scrub understorey)

Wet sclerophyll forest (regrowth with oldgrowth eucalypts and a myrtle, wattle and scrub understorey)

Wet sclerophyll forest (medium dense oldgrowth with a wattle and scrun understorey)

Wet sclerophyll forest (*Leptospermum-Melaleuca* scrubby margin)

Dry Sclerophyll (dense with broadleaf shrub understorey at margin of wet sclerophyll)

Dry sclerophyll forest (dense eucalypts with scrub understorey)

Dry sclerophyll forest (medium dense eucalypts with scrub understorey)

Dry sclerophyll forest (moderately open *Casuarina littoralis* understorey, predominantly in areas of rapid drainage)

Dry sclerophyll forest (pure *Casuarina stricta*, coastal)

Dry sclerophyll forest (closed prickly shrub predominantly in poorly drained areas)

Moorland

Grassland (mainly *Poa*, in Paradise Plain area)

Button grass/sedgeland (*Gymnoschoenus sphaerocephalus* mainly in Mathinna plains and where understorey exposed by tree removal)

Grassland (mixed shortgrasses, mainly in Blue Tier area)

Coastal heath

Fully developed agricultural/pasture land with dense crops and forage

Fully developed agricultural/pasture land with sparse grown crops and forage

Recently cleared forest and coastal heath

Agricultural/pastoral land with remnant eucalypts

Very rough grazing land (disturbed ground surface, mainly in Diddleum plain)

Wet coastal heath and wetlands

Fire burnt patches, logged and burnt areas, bare ground and ploughed fields (mainly inland)

Burnt coastal heath and patchy open woodland

Sand dunes and tin mines

Urban areas and farm buildings

Dieback

Table 5.5

Description of 12 broad land cover classes mapped in Scottsdale District, north east Tasmania, Australia

Label	Class Description	No. of sites visited
PP	Pine plantation	31
RF	Rainforest	16
MF	Mixed forest (eucalypts with rainforest understorey)	28
WS	Wet sclerophyll forest	50
DS	Dry sclerophyll forest	59
AP	Agricultural and pasture land	79
GL	Grassland	21
CH	Coastal heath and patchy open woodland	37
BP	Bare soil, burnt areas and ploughed fields	07
UA	Urban areas and farm buildings	14
SD	Sand dunes and tin mines	15
DB	Dieback	16

and map data are necessary.

A classification accuracy of 85 percent has been reported in the literature (Anderson <u>et</u> <u>al</u>., 1976) as being a minimum acceptable value. Estimation of classification accuracy is extremely difficult if the information about the number and type of spectral classes is unknown before classification. Robinov (1981) pointed out that the measurement of accuracy depends upon a standard which in most cases cannot be rigorously defined. If one is dealing with a totally discrete and unambiguous classification, for example forest land versus non forest land or water versus land, where there can be no argument among interpreters as to the class assigned a given pixel, then high accuracy can be approached. If, however, various classes in a continuum of terrain features are to be identified and mapped, there may be little agreement among interpreters as to the number or type of classes. This situation can be exemplified by taking an example of density of vegetation cover. Should density be measured to the nearest 5%, 10%, 20%, or at what level? Some researchers argue that density cannot really be measured accurately on the ground. For many cover types, this parameter can be measured more accurately with aerial photographs than by ground based procedures. In land cover mapping other questions may be raised such as

. how many classes can be discriminated?
. what is their significance in management and planning?
. how well can the multispectral scanner data be used to differentiate the desired units?

. for what purpose and at what scale is vegetation mapping required?

Once the answers to these questions are determined, the potential and usefulness of multispectral scanner data can then be properly evaluated.

5.9.2 ACCURACY ASSESSMENT TECHNIQUES

Several different techniques have been developed and used to evaluate the remotely sensed data based classification results. These accuracy assessment techniques can be categorized into two groups: qualitative and quantitative. Each technique has some merits and demerits when applied under different conditions. For further details of these techniques see Chapter 2, section 2.4.

Heller (1976) pointed out the need for developing sound sampling procedures to evaluate the accuracy of resource parameters with specific confidence statements based on user objectives. He argued that map products and tabular data presented in such a manner would gain wider user acceptance. Furthermore, they would be in a format that would allow a resource manager to make decisions on the value of the data and incorporate such data into his management decisions.

Comments made by Mead and Szajgin (1981) are also worth mentioning because they are relevant to this discussion. They argued that one should not lose track of the difference between the usefulness of a specific product and its estimated accuracy. A numerical report of product accuracy may say nothing of how much use the product gets or how well it compares with what was previously available. In many instances a classification of low or intermediate accuracy is a welcome and useful product. This is especially valid in those areas where existing land cover information is limited. For example, there is no land use map of Tasmania, especially at the scale of 1: 500 000. Such information extracted from remotely sensed data could fill an important data gap in the state.

5.9.3 ACCURACY ASSESSMENT TECHNIQUE FOLLOWED IN THIS PROJECT

From the statistical point of view, it would have been ideal to follow a stratified random sampling technique in collecting ground truth data, and to rigorously assess the accuracy of the Landsat based classification. This technique ensures that all land cover types are taken into consideration. However, in this study, the resources required to follow this technique for 29 land cover classes identified in this project would have been excessive in terms of the time and financial constraints.

Every forest block was visited as part of the accuracy assessment. Emphasis was given to those blocks where most of the land cover classes existed. Landsat based classification maps, photo-interpretation type maps and vegetation type maps were taken to the field. Field staff who had a detailed knowledge of the study area were present. Before collection of the field data, 29 land cover classes were merged into 12 broad groups (see Table 5.4 and 5.5). Each of the forest blocks was traversed and efforts were made to record information of those sites which could confidently be identified on the ground, map and image. Certain land cover classes (such as button grass, sand dunes and pine plantation) which are site specific were also visited and their accuracy level was determined.

The resulting table showing the level of agreement (or disagreement) between the Landsat based labels and the field assessed labels is shown in Table 5.6. The rows of Table 5.6 show the field labels, as defined in Table 5.5 and the columns show the equivalent Landsat based interpretations. Table 5.7 (the confusion matrix) has been column normalised so that errors of omission and commission are spread across all pixels in a class.

This normalizing technique overcomes some of the area bias in field sampling (which arises from sampling by forest blocks rather than spectral class) and provides an estimate of the matrix which theoretically would result if every pixel were tested. In area terms, the agreement (the percent of area on the diagonal) was 89.66 percent (Table 5.7) which is totally satisfactory for the purpose of a broad scale inventory.

From Table 5.7, it emerges that pine plantation, coastal heath, urban areas and dieback have low accuracy level compared to other land cover classes. During the field work, it was observed that misclassification of pine plantation was mostly either because of the lack of distinction between very young pine plantation and very young eucalyptus regrowth in wet sclerophyll forest areas (see Figure 5.19). Confusion also arose when blue greyish wattle trees, very young myrtle and dolly bush (mainly Bedfordia spp) were found with four to five years old pine plantation areas (see Figure 5.20).

Table 5.6

Contingency table

Land cover classes with symbol		(PP)	(RF)	(MF)	(WS)	(DS)	(AP)	(GL)	(CH)	(DB)	(BP)	(UA)	(SD)	Row total
Pine plantation	(PP)	27	2		1						1			31
Rainforest	(RF)		14	2										16
Mixed forest	(MF)		3	23	1									27
Wet sclerophyll forest	(WS)	2	1	2	44		1							50
Dry sclerophyll forest	(DS)			1	3	53		1	1					59
Agricultural/pasture land	(AP)	1			1	2	71		2			2		79
Grassland	(GL)						2	16					3	21
Coastal heath	(CH)						2		33	2		2		39
Dieback	(DB)					1			2	12	1			16
Bare soil, ploughed fields	(BP)						1				5	1		7
Urban areas, farm buildings	(UA)						1		2			11		14
Sand dunes, tin mines	(SD)											2	13	15
Column total		30	20	28	50	56	78	17	40	14	7	18	16	322

Table 5.7

Normalized error matrix

Land cover classes with symbol		(PP)	(RF)	(MF)	(WS)	(DS)	(AP)	(GL)	(CH)	(DB)	(BP)	(UA)	(SD)	Row total	% purity
Pine plantation	(PP)	22340	2280		4582						1175			30377	73.54
Rainforest	(RF)		15959	2355										18314	87.14
Mixed forest	(MF)		3420	27080	4582									35082	77.19
Wet sclerophyll forest	(WS)	1655	1140	2355	201609		2586							209345	96.30
Dry sclerophyll forest	(DS)			1177	13746	220245		2092	138					237399	92.77
Agricultural/pasture land	(AP)	827			4582	8311	183628		276			419		198043	92.72
Grassland	(GL)						5173	33471					1370	40014	83.65
Coastal heath	(CH)						5173		4548	1933		419		12072	37.68
Dieback	(DB)					4156			276	11595	1175			17202	67.41
Bare soil, ploughed fields	(BP)						2586				5877	209		8673	67.76
Urban areas, farm buildings	(UA)						2586		276			2303		5165	44.59
Sand dunes, tin mines	(SD)											419	5937	6356	93.41
Column total		24822	22799	32967	229101	232712	201732	35563	5513	13528	8228	3769	7307	818041	
Percent purity		90	70	82	88	95	91	94	83	86	71	61	81		89.79

Figure 5.19 : Young pine and eucalyptus regrowth.

Figure 5.20 : Mixture of wattle, young myrtle and dolly bush.

Misclassification in the coastal heath was found to be mainly due to the spectral similarity between the disturbed grazing areas, urban areas and dieback eucalytus in the coastal areas and along newly developed agriculture and pasture land.

The dieback area was misclassified as coastal heath and dry sclerophyll forest. Urban areas were found to spectrally overlap with agricultural land and coastal heath. This confusion is not, however, of great consequence as these classes, especially coastal heath and urban areas, carried less importance in the overall mapping context of the project. However, it does show that where the objective is direct mapping and monitoring of spectrally confusing classes, analysis of sequential Landsat images or the use of finer resolution data as provided by the Landsat TM or SPOT satellites is likely to be necessary.

The mapping accuracy for the confused classes was improved by integrating ancillary information into the system as described in the next section. This allowed different labelling in different forest blocks for spectrally similar classes.

5.9.4 POST CLASSIFICATION REFINEMENT

During the analysis, spectral similarity was observed between different land cover classes. For example, similar spectral signatures were obtained for young pine plantations, wattle trees and rainforests, as well as between sand dunes and tin mining areas. Similarly, old pine plantation overlapped with wet sclerophyll forests. Keeping in mind the a-priori information about the spatial distribution of various land cover classes, this problem was largely resolved by labelling overlapped classes differently in different forest blocks. However, the overlap problem could not be resolved in those forest blocks where both of the spectrally overlapping classes existed. As a result of the relabelling exercise, the accuracy level for coastal heath and pine plantation increased from 74 and 71 percent to 77 and 82 percent respectively.

CHAPTER 6

DETECTING CHANGES IN LAND COVER USING LANDSAT MSS DATA

6.1 INTRODUCTION

Proper management of natural resources depends on the development of efficient resource information techniques. The most desirable features sought in such techniques are an ability to acquire, analyze and provide timely information at regular intervals. Information about land cover change is extremely important in a forest environment. Since this renewable resource continues to decrease, therefore increasing the need for better management and utilization.

The detection, classification and measurement of land cover change is an extremely complex task. As discussed in Chapter 1, many current techniques for detection of change and inventory of forest resources are not as effective or efficient as desired. Therefore, there is a need to develop alternate techniques for acquiring this information.

In GIS terms, the data that transfers most easily into the data base are a set of transition matrices, showing changes in area of each land cover, stratified by management zone. The generation of these tables, together with some measure of their reliability, is a prime objective of most monitoring schemes.

Satellite data offers one solution to the above need since firstly, they provide time and cost effective information to update existing land cover data and maps. Secondly, they provide information in map, image, graphic or tabular form for use in change analysis, modelling and other applications.

Recently, Landsat MSS data based techniques have been successfully used for monitoring the above mentioned changes. These techniques rely on the changes being visible in the spectral characteristics of various land cover types. However, extreme caution is required when using such techniques for monitoring actual changes in a land cover of interest, as the observed changes in the spectral characteristics on the Landsat images are also influenced by a number of other factors. Among these, the most significant factors include differences in sun angle, season of the year, background exposure and differences in soil moisture content.

In this Chapter, firstly, the spectral change detection methods and classification based, change detection techniques are reviewed. Secondly, the application of spectral change detection techniques to the north east Tasmanian environment is considered. Finally, an approach used for enumerating changes in different land cover types in the study area is discussed.

6.2 MULTI-IMAGE REGISTRATION

In order to perform multi-temporal analysis, it is essential to register different data sets so that a given pixel in the time t_1 image overlays precisely its equivalent pixel in the time t_2 image. The need to bring about a one to one relationship between pixels in different images arises because of the fact that images taken over the same region by the same or different spacecraft are not spatially registered. This is mainly due to the variations in different factors such as earth rotation, earth curvature, altitude and attitude, sensor alignment and scan speed variation. In this project, these distortions were eliminated in the rectification process by using a satellite model. For details see Appendix A3.5.

After removing the distortions through the image rectification procedure, two images can either be directly registered by resampling one directly to the other or they may be resampled to a common map base using transformation equations as discussed below. The former technique can be precise, but resampling to a common base is preferred when there are several data sets to be registered.

Let (l , p) and (l', p') represent the line and pixel coordinates for images taken at two times. If the coordinate system of the base map is (x , y) then the image to map registration process is to estimate two transformations:

$$\begin{array}{ll} & T_1 \quad (x , y) ---- (l , p) \\ \text{and} & \\ & T_2 \quad (x , y) ---- (l', p') \end{array} \qquad (6.1)$$

The coefficients of the transformations T_1 and T_2 can be estimated using least squares and a set of control points which can be common to any two or (preferably) all three images, that is, the image for time t_1, the image for time t_2 and the base map. The resampling process then selects data from each of the images corresponding to a standardized geographic grid x , y. The GCP selection method used for estimating different transformation parameters is discussed in detail in Appendix

A3.5.

The transformation functions T_1 and T_2 were used to transform the two images (1980 and 1984) to a common map base with a two second grid. The registration accuracy achieved in the project was within the level of half a pixel which was considered extremely satisfactory. This was most probably achieved because of the high number of ground control points used and the rectification of parts of the Landsat scenes covering the study area rather than the full Landsat scene.

The method used in the project to register the images was nearest neighbour resampling which has been discussed by Bernstein and Ferneyhough (1975). This method is preferred over the others because of its property of retaining the original values rather than producing a transformed data set.

6.3 SPECTRAL CHANGE DETECTION METHODS

Once data are accurately registered spatially, the next step is to enumerate changes. A number of techniques have been reported which have been used for spectral change detection analysis. These techniques include image differencing (Anuta, 1973; Weismiller, et al., 1977; McKinney and Stauffer, 1978; Riordan, 1980 and Likens and Waw, 1982), band ratioing (Todd, 1977; Wilson et al., 1976; Angelici et al., 1977; Howarth and Wickware, 1981; and Werth, 1982), albedo differencing (Robinove et al., 1981), change vector analysis (Thomson, et al., 1979; Malila, 1980 and Colwell and Weber, 1981) and principal component analysis (Williams and Borden, 1977; Abotteen, 1978; Lodwick, 1979; and Byrne, et al., 1980). These techniques are reviewed below:

6.3.1 IMAGE DIFFERENCING TECHNIQUE

This technique is based on the classification of a difference data set. Here, after registration, data taken at time period t_1 is subtracted from the second data set taken at time period t_2. Mathematically, this can be expressed as:

$$\Delta X_{lpk} = x(t_1)_{lpk} - x(t_2)_{lpk} + c \qquad (6.2)$$

where Δ X is the difference image, $x(t_1)$, $x(t_2)$ are the images taken at two different time periods, c is a constant, l is line number, p is pixel number and k is a channel number.

The subtraction results in an image in which positive and negative values about the offset c represent areas of change and zero values represent areas of no change. This technique yields a differenced distribution that approximates a normal bell shaped curve in which pixels of greatest radiance change are distributed in the tails of the distribution (Estes et al., 1982). Using histograms of each band, breakpoints are then defined in the distribution tail for change delineation.

A major drawback of this technique is its difficulty in accurately thresholding the spectral distribution for demarcating the changed and unchanged pixels. Moreover, this technique is also extremely sensitive to misregistration and may be dominated by spectral change of low interest to the interpreter such as seasonal state or a different sun position.

6.3.2 BAND RATIOING TECHNIQUE

In this technique after removing the atmospheric scattering effect from the remotely sensed data, the spectral response in some of the selected bands at time t_1 is divided by the response at time t_2. This technique is preferred to differencing where the changes are multiplicative rather than additive. In the literature the use of band 5 and band 7 has been mostly reported for monitoring temporal changes (Todd, 1977; Weismiller et al., 1977 and Nelson, 1981). Band ratioing generally produces an enhanced image and highlights changed areas. The changed areas are then either classified using pattern recognition techniques or the desired information is inferred by comparing it with existing resource related maps. For the effective use of this technique Todd (1977) recommended that the different images selected for analysis must be seasonally coincident to minimize spectral differences resulting from phenology and season. This technique requires only single classification, but its major drawback is the fact that it is extremely complex and often requires many classes of little use to the interpreter.

6.3.3 THE ALBEDO DIFFERENCING TECHNIQUE

This technique involves the calculation of the earth's albedo, as measured by the remotely sensed data from different dates and then analyzing the increase or decrease in albedo. Albedo is the ratio of the amount of electromagnetic radiation reflected by a surface to the amount of incident radiation upon it. In this technique, for every pixel in the Landsat scene, the albedo values are calculated and then albedo difference images are created by subtracting albedo values of two successive Landsat images:

$$\text{Albedo} = R_k \, (B_k - B_{mink})/S_k \sin\theta \qquad (6.3)$$

where

B_k = Mss band 4 to 7 digital counts

B_{mink} = minimum reflectance value due to atmospheric backscattering in band k

S_k = the average solar irradiance at the top of the atmosphere in W/cm^2 in band k

R_k = factor to convert the digital counts to irradiances, and

$\sin\theta$ = correction factor which allows calculation of albedo as though the sun were at zenith

For the derivation of Equation 6.3 and the details of the albedo difference algorithm see Robinove et al. (1981). Although this technique is considered fairly useful for detecting changes in land cover, determining an accurate change thresholding value is very difficult. Moreover, as pointed out by Frank (1984), the model used to construct the albedo images cannot fully account for all extrinsic environmental and atmospheric factors that also affect reflectance changes.

6.3.4 CHANGE VECTOR ANALYSIS TECHNIQUE (CVA)

This technique calculates the spectral change vectors from Landsat data taken at two different times. Here, two scenes are first registered spatially and then using PCA analysis, raw spectral data are transformed into brightness (first principal component) and greenness (second principal component). CVA analysis is made on the basis of clusters of Landsat data which have spectral/spatial similarity. Such clusters of data are called blobs (Kauth, et al., 1977). By forming two blobs at two dates, the magnitude of the change vector is assessed which is described in Figure 6.1. In the figure, the spectral characteristics are plotted in greenness and brightness for two different dates. The spectral change from date 1 to date 2 can be described in terms of the angle of change and the vector magnitude ($\Delta G^2 + \Delta B^2$) of change. It is by analysis of this change vector magnitude and angle that the CVA procedure indicates whether a change has taken place and what kind of change it is likely to be (Colwell and Weber, 1981).

This technique seems more sophisticated than the ones previously mentioned. Like other techniques, accurate spatial registration is very critical. Slight spatial misregistration can lead to false indications of change. Since this is a recently developed technique and very few researchers have used it, there is a need to check its validity under different environmental conditions.

6.3.5 PRINCIPAL COMPONENT ANALYSIS (PCA) TECHNIQUE

The technique of PCA analysis has also been used by many researchers for monitoring temporal changes. In using multi-date images, the analyst is confronted with massive computational problems in terms of data volume. This leads to the need of using more expensive and sophisticated systems which can handle imagery with a large number of channels, or the channels must be reduced by data transformation.

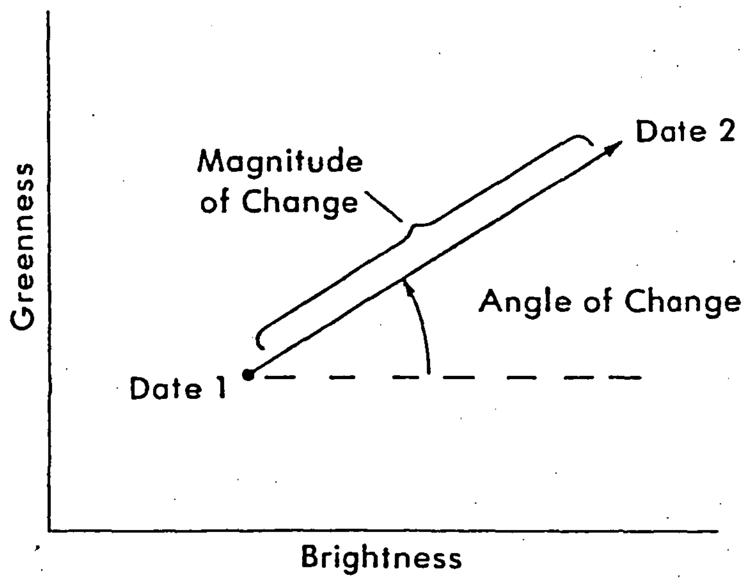


Figure 6.1 : Illustration of spectral change vector·
(Adopted from Colwell and Weber, 1981)

Principal component analysis applied to multispectral data produces a series of linear transformations of the raw data and results in a new set of mutually orthogonal variables. The process is performed in such a way that each new variable accounts for a successively smaller amount of the total variance. For Landsat MSS data, the first two principal components often account for up to 98 percent of the total variation. Therefore, the remaining components can be eliminated from the analysis without much loss of the information.

For temporal changes, the principal components corresponding to changes between different date images are used. Changes can then be identified and labelled by using pattern recognition techniques.

6.4 APPLICATION OF SPECTRAL CHANGE DETECTION TO NORTH EAST TASMANIA

In monitoring temporal changes, some researchers (Wickware and Howarth, 1981; Likens <u>et al</u>., 1982 and Colwell <u>et al</u>., 1982) used differences in means and variances in the Landsat channels of two images of an area. These differences may be due to actual variations in the land cover classes being investigated or they may be due to variations in external factors such as atmospheric differences, different sun angle or satellite performance parameters (e.g Landsat 2 versus Landsat 5). All those external factors which affect the radiometric quality of the Landsat MSS data need to be accounted for in this analysis. In this project, the data was radiometrically corrected using the calibration procedure suggested by Malila and Anderson (1986). Their procedure is summarized in the following section.

6.4.1 DATA CALIBRATION

Malila and Anderson (1986) employed both pre-launch and post- launch calibration procedures for the Landsat MSS systems. The pre-launch procedure employs a large-aperture integrating-sphere calibration source which is stepped through a representative range of intensities. The dynamic range of each channel is determined and the least responsive channel in each band is identified and used for the calibrated output for the band.

They also pointed out that each MSS has an internal calibration lamp which is viewed by each detector through a variable density filter. This produces a calibration-wedge signal which is sampled at several different positions at the end of every mirror sweep. Regression coefficients (C_i and D_i) are established during preflight calibrations, based on individual channel responses to the calibration-wedge samples.

In post-launch ground processing of image data, the channel responses to the calibration sources are used with the C_i and D_i coefficients to compute individual channel gains and offsets. These gains and offsets are computed for every other scan line and are filtered along the satellite track to smooth any variations in the values. The filtered gains and coefficients are then used with the look up tables to equalize the responses of the individual detectors in each band, produce the desired dynamic ranges and then radiometrically correct raw image data values.

By using the above procedure, they reported variable consistency in removing banding and striping artifacts from Landsat MSS data. Therefore, they used an additional process: a histogram balancing process. This process adjusts the channel gains and offsets so that, within each band, the channel means and standard deviations become the same as the average band value. Each image is then divided into segments with revised gain and offset values being determined for each segment. These values are blended between segments before being applied, with updates typically being made for every 200 lines.

Finally, the balanced digital values are converted to absolute radiance values through the use of maximum and minimum radiance values. For data having a 255 count range, the relationship can be expressed as:

$$L = \left[\frac{L_{max} - L_{min}}{255}\right] Q + L_{min} \qquad (6.4)$$

where

L_{max} = The radiance value corresponding to the maximum counts on the output CCT

L_{min} = The radiance value corresponding to zero counts

Q = Radiometrically balanced data value in digital counts

Values for L_{max} and L_{min} differ from satellite to satellite and from time to time for a given satellite. Markham (1985) summarized the calibrated dynamic range for Landsat MSS data which is reproduced here as Table 6.1. Calibration values for the two Landsat images used in the analysis were then selected and

TABLE 6.1

MSS POST CALIBRATION DYNAMIC RANGES
(Within Nominal Bandpass Radiances-
mW/cm^2 ster)

SATELLITE APPLICABLE DATES *	BAND 1 (0.5-0.6 μm) $LMIN_N$	BAND 1 (0.5-0.6 μm) $LMAX_N$	BAND 2 (0.6-0.7 μm) $LMIN_N$	BAND 2 (0.6-0.7 μm) $LMAX_N$	BAND 3 (0.7-0.8 μm) $LMIN_N$	BAND 3 (0.7-0.8 μm) $LMAX_N$	BAND 4 (0.8-1.1 μm $LMIN_N$	BAND 4 (0.8-1.1 μm $LMAX_N$
LANDSAT-1								
ALL	0.00	2.48	0.00	2.00	0.00	1.76	0.00	4.60+
LANDSAT-2								
< 7/16/75	0.10	2.10	0.07	1.56	0.07	1.40	0.14	4.15
> 7/16/75	0.08	2.63	0.06	1.76	0.06	1.52	0.11	3.91
LANDSAT-3								
< 6/1/78	0.04	2.20	0.03	1.75	0.03	1.45	0.03	4.41
> 6/1/78**	0.04	2.59	0.03	1.79	0.03	1.49	0.03	3.83
LANDSAT-4								
< 8/26/82***	0.02	2.50	0.04	1.80	0.04	1.50	0.10	4.00
8/26/82-3/31/83	0.02	2.30	0.04	1.80	0.04	1.30	0.10	4.00
> 4/1/83	0.04	2.38	0.04	1.64	0.05	1.42	0.12	3.49
LANDSAT-5								
< 4/6/84***	0.04	2.40	0.03	1.70	0.04	1.50	0.08	3.80
4/6/84-11/08/84	0.03	2.68	0.03	1.79	0.04	1.59	0.11	3.69
> 11/09/84	0.03	2.68	0.03	1.79	0.05	1.48	0.11	3.69

* Landsat 1-3 dates are processing dates; Landsat 4,5 are acquisition dates, at 0000 GMT

** Some data acquired as early as 4/24/78 were processed with these parameters

*** Reproduction periods--limited data available

\+ Landsat 1, Band 4 data were not calibrated post launch with the Internal Calibrator.

Source: Markham (1985)

incorporated in the calibration process.

In this study, data calibration for change image analysis was performed in the following three steps:

1. the raw data was despiked using the mSMOOO program in the microBRIAN software. This program allows the removal of aberrant spectral values or spikes from the data.
2. atmospheric path or dark values were calculated using Switzer's (1981) method. For further details of this method see Chapter 5.
3. Lastly, the data was balanced and calibrated using Table 6.1 from Malila and Anderson (1986).

6.4.2 CHANGE IMAGE ANALYSIS

Following data calibration, Principal Component Analysis (PCA) and image differencing were used to detect the spectral changes.

Because PCA is an effective data compression technique, it is widely applied for measuring changes using Landsat multi-temporal data. In Landsat MSS data, using a variance-covariance matrix one finds that the first principal component (PC1) is positively weighted on the basis of the size of channel standard deviation, whilst, PC2 represents the difference between the visible and infrared bands. The last two components usually contain very little variance and are dominated by noise.

It is generally assumed that the first principal component measures brightness which is related to the form of terrain, amount and colour of exposed soil, and perennial vegetation cover. The second principal component differentiates quantity and quality of greenness because of the high absorption by green vegetation in the visible bands and high reflectance in the infrared. These two most important parameters (greenness and brightness) can, therefore, very effectively be used for detecting spectral changes in the two Landsat scenes.

In this thesis, principal components transformations were applied to the 1980 and 1984 Landsat images (Figures 6.2 and 6.3). The first two principal components accounted for 98 and 94 percent of the variance in the 1980 and 1984 images respectively. The loadings of the principal vectors (Table 6.2) shows how the common interpretation of PC1 as brightness and PC2 as greenness holds also in this case. That is, PC1 has all positive weights and PC2 has positive loadings on the visible channels and negative on the near infra-red. These components were derived as images and also used to assess spectral change between the dates by brightness (Figures 6.4 to 6.7), greenness (Figures 6.8 to 6.11) and the composite of brightness and greenness (Figure 6.12).

The differences in brightness and greenness were evaluated by forming a stack image consisting of the four channels ($PC1_{80}$ $PC2_{80}$ $PC1_{84}$ $PC1_{84}$) and subjecting it to principal component analysis. The result is summarized in Table 6.2 and its loadings provide interpretation of PC2 as change in brightness (Figure 6.6) and PC3 as change in greenness (Figure 6.10).

Figures 6.4 and 6.5 are the first principal component images

Table 6.2

Percent of Variance for Principal Components from November 1984 and May 1980 Landsat MSS data

Principal component	Band 4	Band 5	Band 6	Band 7	Percent variance
		---1980---			
PC1	.4176	.3084	.6202	.5881	81.6
PC2	.5481	.6559	-.2820	-.4357	16.6
PC3	-.7213	.6846	.0739	.0753	1.5
PC4	.0702	.0781	-.7283	.6772	0.4
		---1984---			
PC1	.4183	.5214	.5927	.4494	80.4
PC2	.3903	.6329	-.4767	-.4689	14.1
PC3	.8157	-.5721	-.0080	-.0850	4.8
PC4	.0853	.0183	-.6492	.7556	0.6
		---stack image--- $(PC1_{80}, PC2_{80}, PC1_{84}, PC2_{84})$			
PC1	.7414	.6620	.0734	.0813	48.4
PC2	-.0827	-.0708	.7426	.6609	29.5
PC3	.3328	-.3882	-.5713	.6420	13.4
PC4	-.5768	.6372	-.3418	.3802	8.8

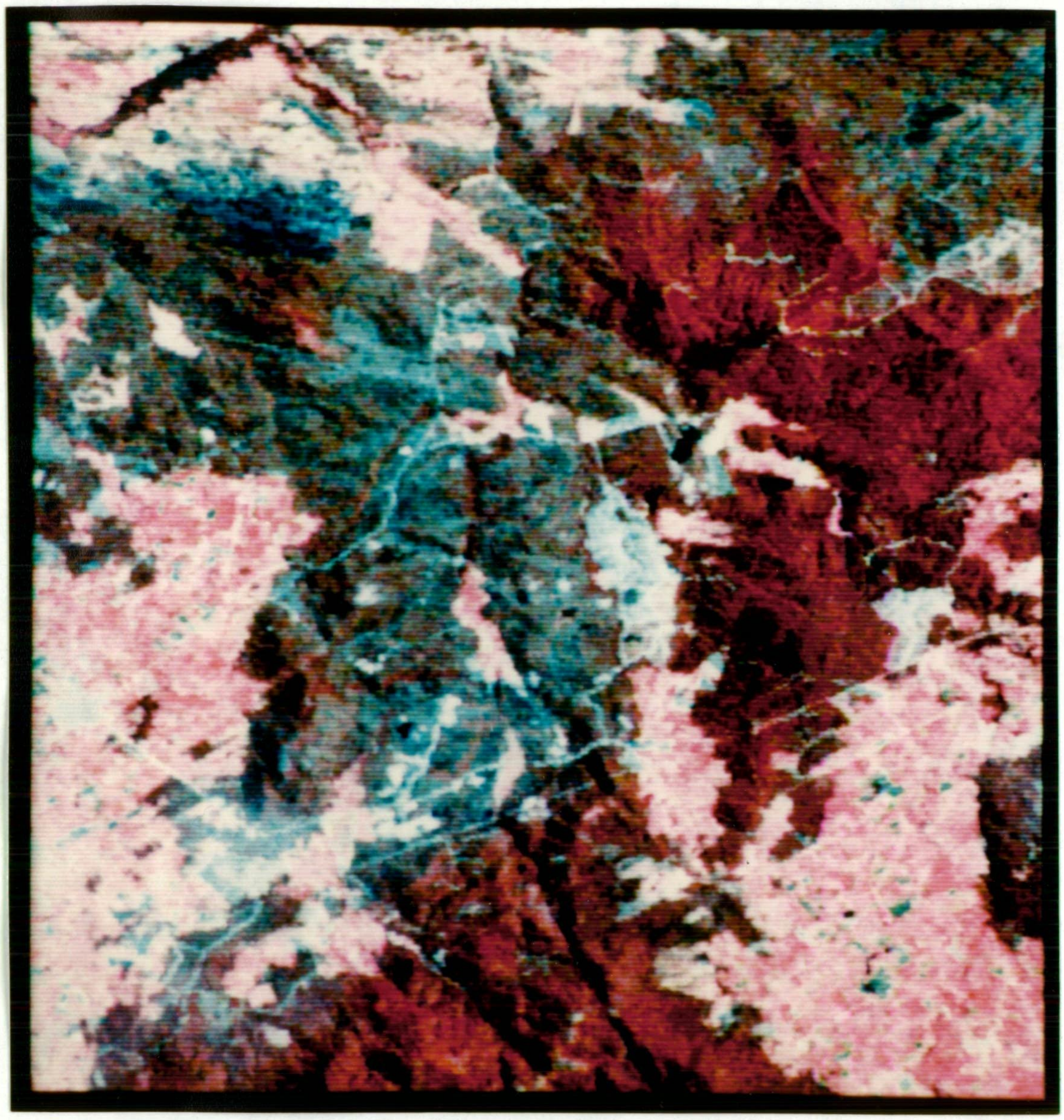


Figure 6.2 : False colour composite image for the representative study area - 1980.

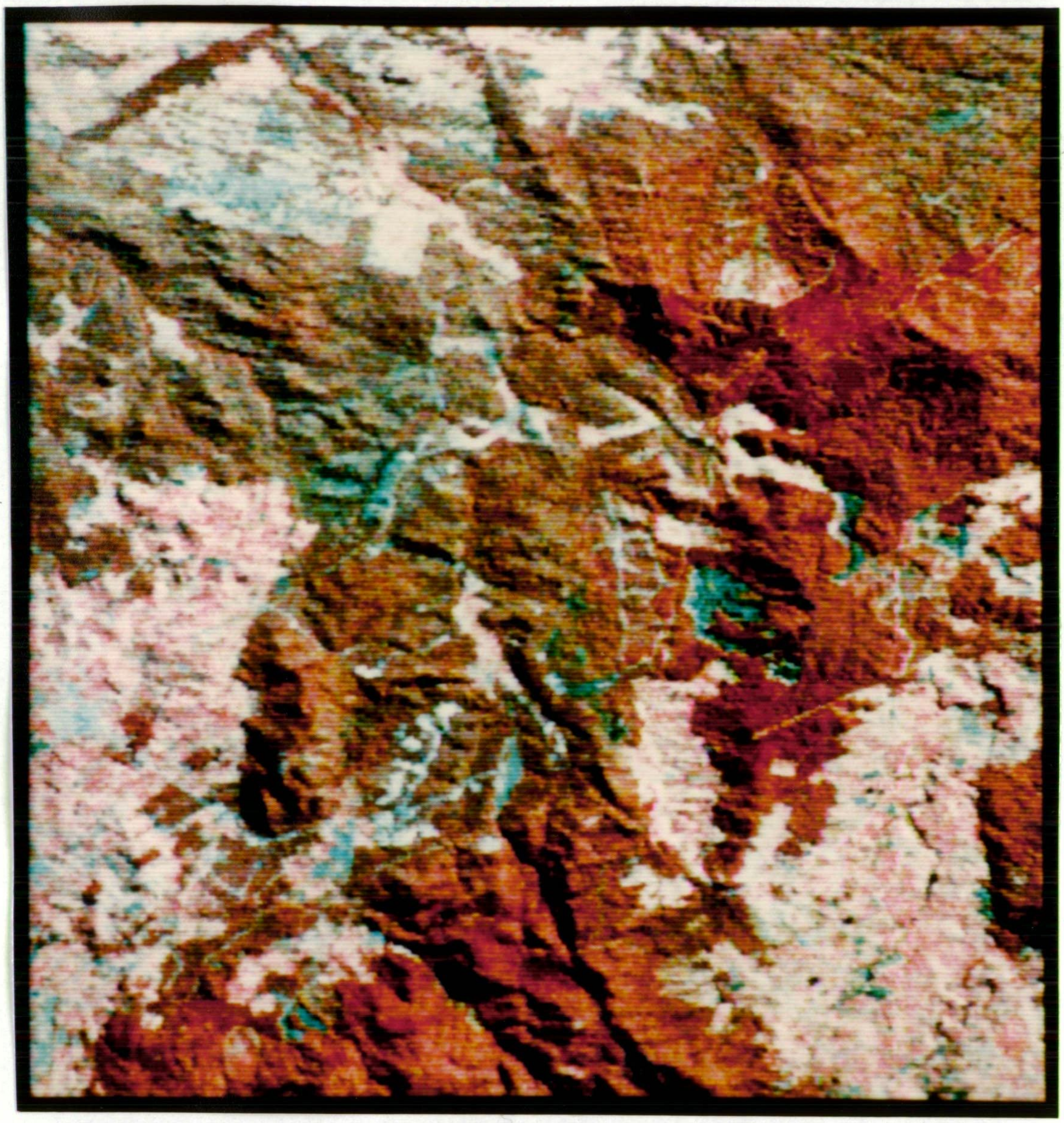


Figure 6.3 : False colour composite image for the representative study area - 1984.

Figure 6.4 : PC1 (brightness) image for the representative study area - 1980.

Figure 6.5 : PC1 (brightness) image for the representative study area - 1984·

Figure 6.6 : Change in brightness (1984-1980) obtained from PC2 of the stack image.
White is high positive change and black is low or negative change.

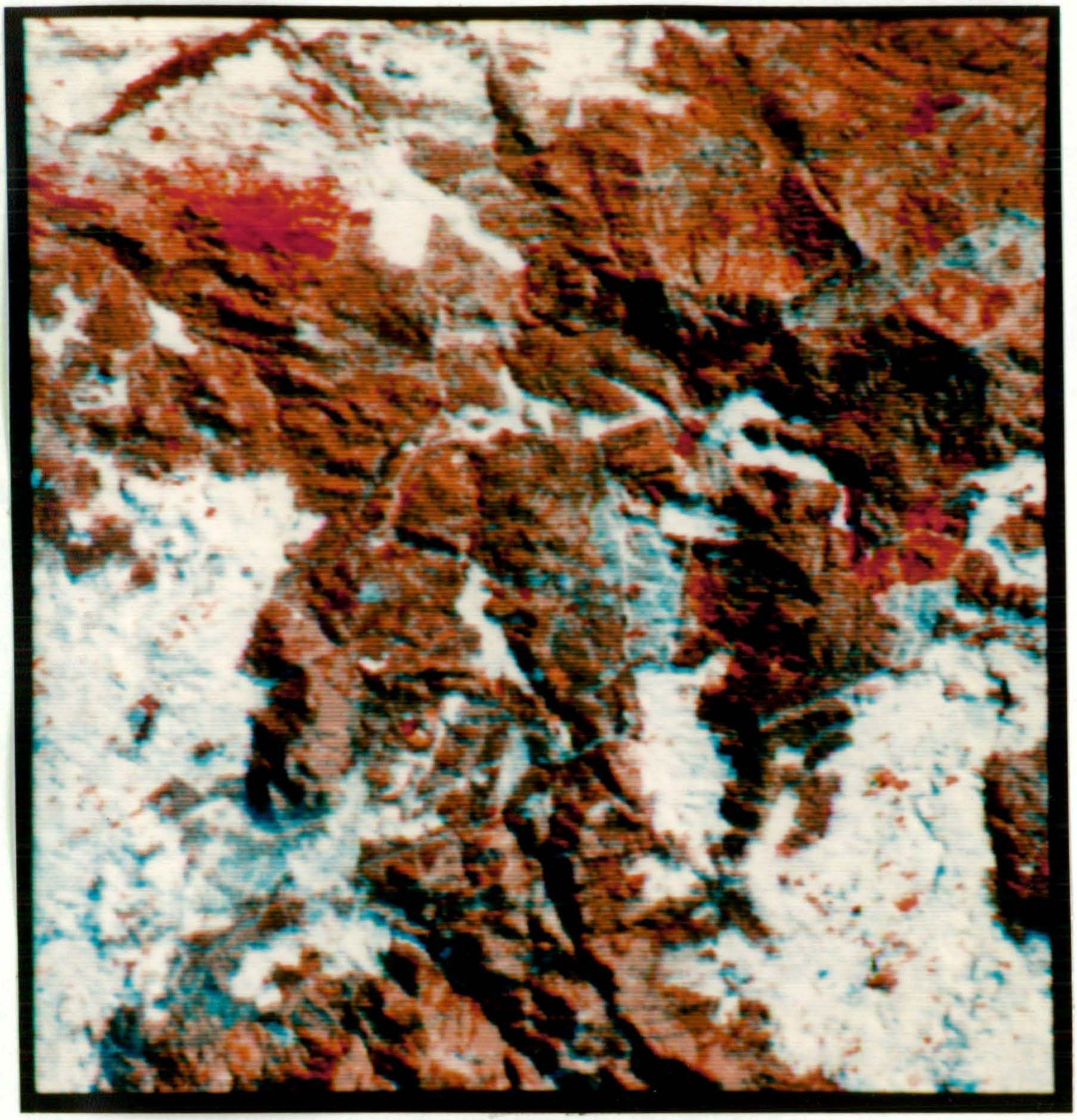


Figure 6.7 : False colour image showing brightness for 1980 and 1984. The 1984 brightness is represented by cyan (blue + green). No change in brightness is represented as white.

Figure 6.8 : PC2 (greenness) image for the representative study area - 1980. Brighter white represents decrease in vegetation.

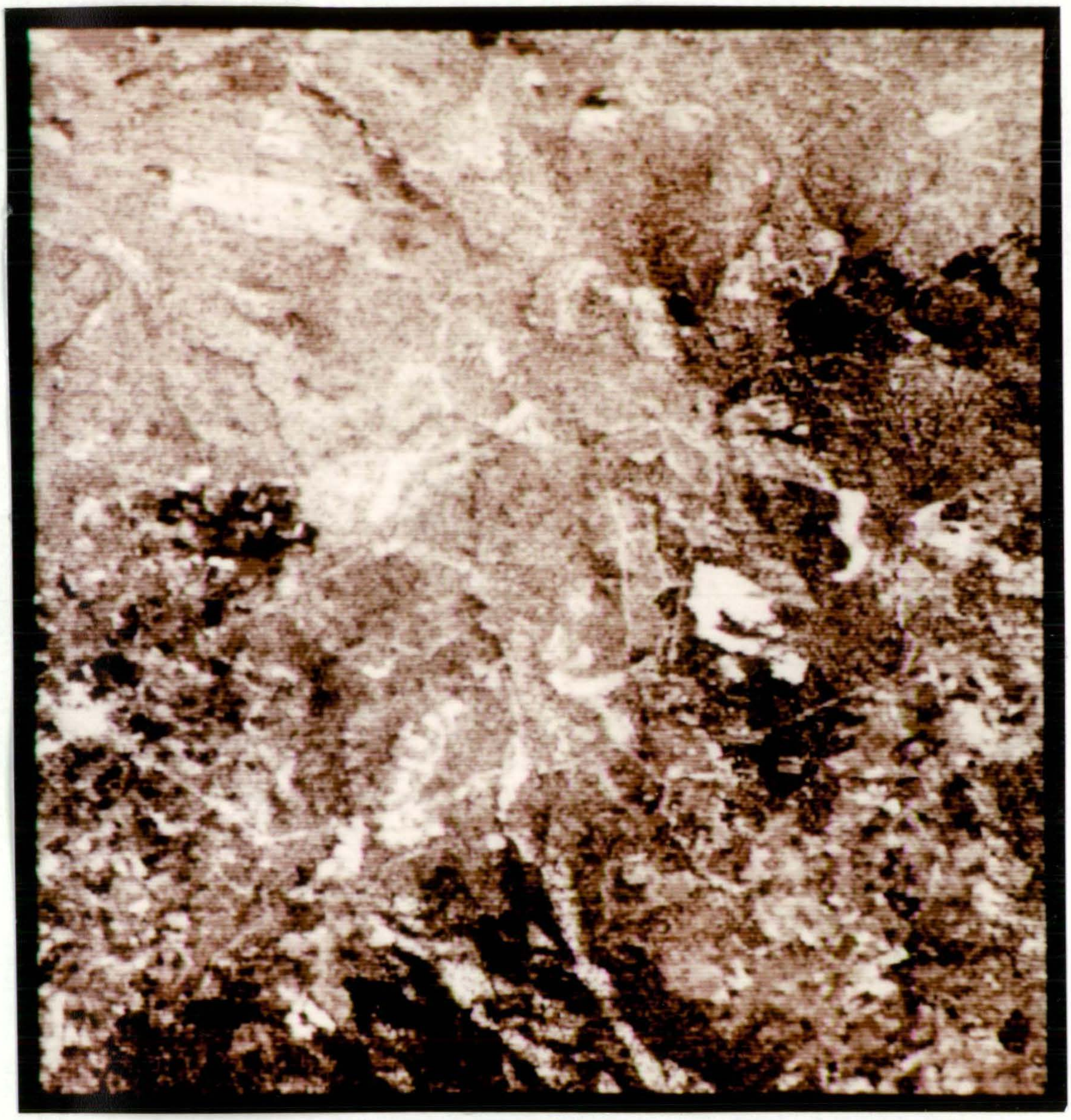


Figure 6.9 : PC2 (greenness) image for the representative study area - 1984. Brighter white represents decrease in vegetation.

Figure 6.10 : Change in greenness (1984-1980) obtained from PC3 of the stack image. Black represents high positive change and white represents low or negative change.

Figure 6.10 : Change in greenness (1984-1980) obtained from PC3 of the stack image. Black represents high positive change and white represents low or negative change.

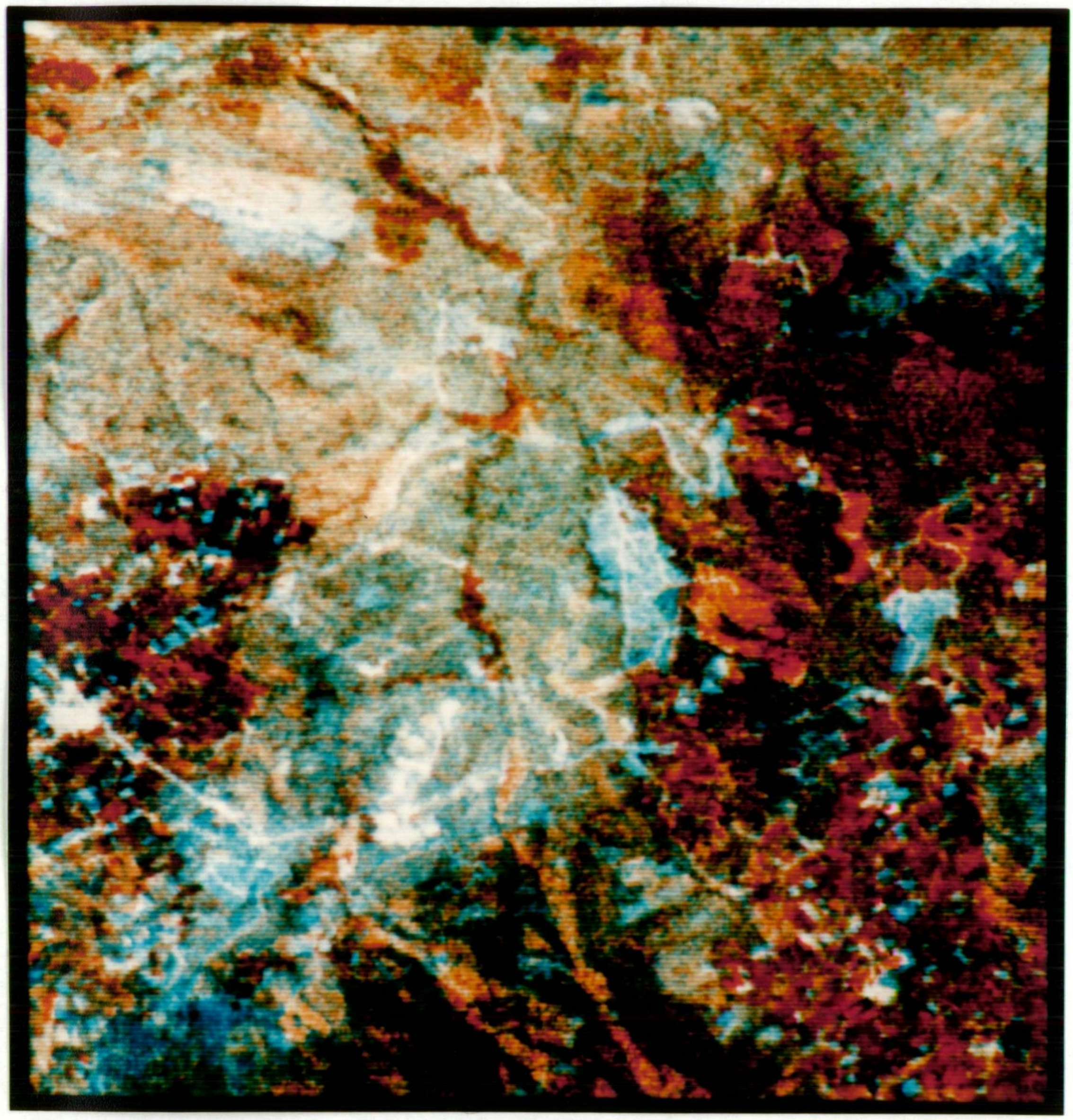


Figure 6.11 : False colour image showing greenness for 1980 and 1984. The 1980 greenness shown as red. 1984 greenness represented by cyan. No change is represented as white.

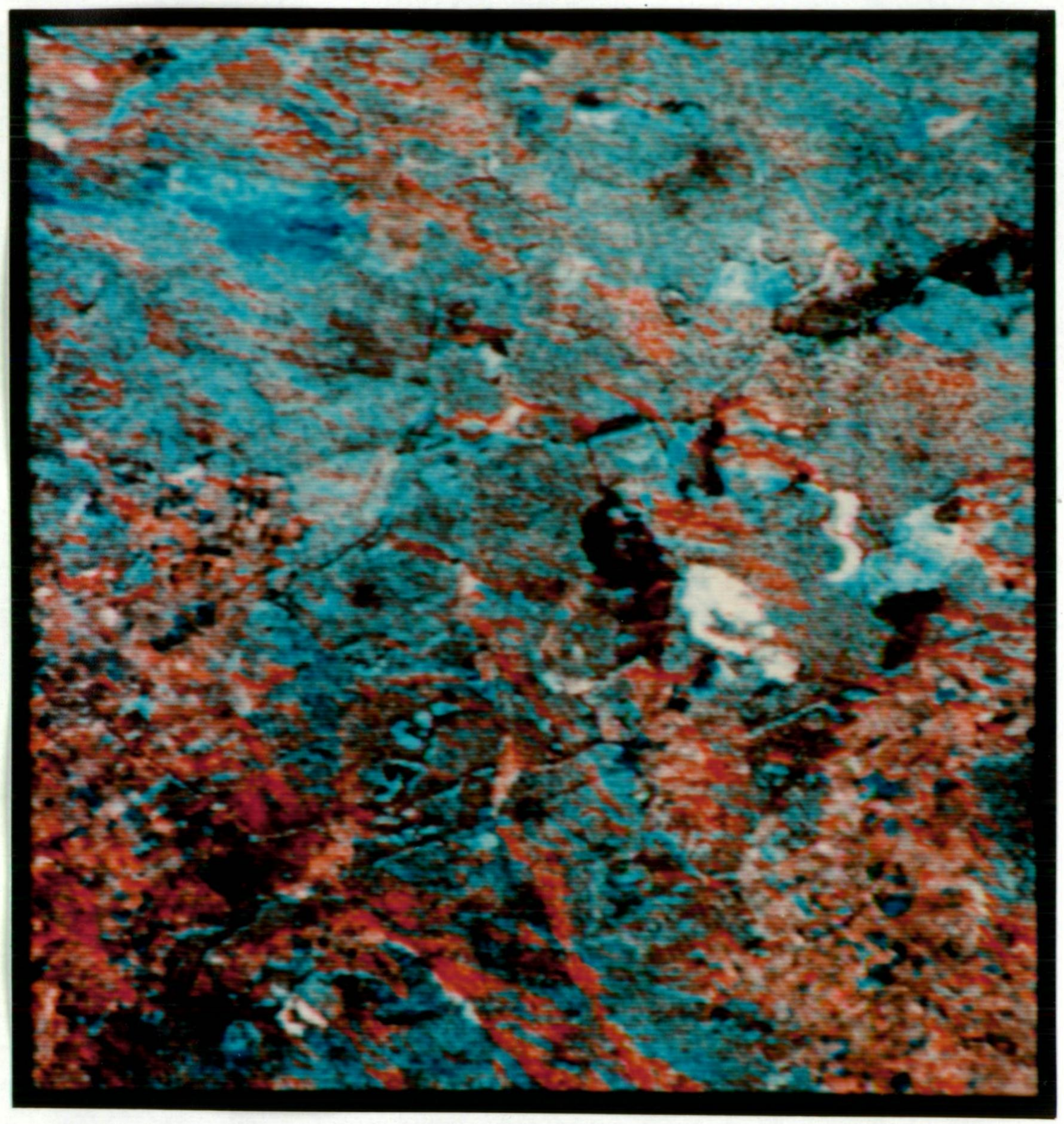


Figure 6.12 : False colour image showing changes in greenness and brightness. Greenness change is represented by cyan whilst a brightness change is represented by red.

of the 1980 and 1984 images respectively. Figure 6.6 highlights changes in brightness from 1980 to 1984. In this image light shades represents high positive change and dark shades represent low or negative change. In the 1980 image, areas that were fire burnt (a), cleared and burnt (b) or ploughed fields (c) are the brightest features (largest positive change) on the changed image. A colour image of this information is shown in Figure 6.7, with 1984 brightness shown as red and 1980 brightness colour coded as cyan (blue + green).

The second principal component (greenness) images of 1980 and 1984 are shown in Figures 6.8 and 6.9 whilst changes in greenness (1984-1980) are shown in Figure 6.10. This was created by plotting the third principal component of the stack image. It can be observed from the change image that an increase in vegetation over time is represented by darker shades (for example see a, b, c and d in Figure 6.10 and their corresponding areas on the raw data images and Figures 6.8 and 6.9). A decrease in vegetation over time is represented by lighter shades. A colour image showing changes in greenness is given in Figure 6.11 where 1980 greenness is red and 1984 greenness is colour-coded as cyan. In this figure, bright red shows a decrease in vegetation whilst an increase in vegetation is represented by a cyan colour.

Figure 6.12 is a colour-coded image depicting changes in greenness and brightness. In this figure changes in greenness are coded as cyan and changes in brightness as red. Areas with a large positive change in both greenness and brightness appear white. The intensity of the two colours is related to the intensity of change. A black colour represents areas with no change in brightness or greenness.

The above approach was compared with another in which geometrically and radiometrically corrected raw data images were resampled and registered to a common base. A four channel difference image was created which allowed changes to be detected on the basis of reflectance differences between the two dates. Before creating a difference image, the two image data sets were equalized using the mFRITE program. This program rescales the effective data range of each image to the full range (0-255), therefore making digital reflectance values in the two images directly comparable.

The difference image shown in Figure 6.13 was created by subtracting the equalized 1980 data from the equalized 1984 data. In this image, an increase in vegetation over time is represented by red whereas, a decrease in vegetation is represented by cyan. Areas where no change occurred appear in light greyish colours that is, an equal mixture of all three primary colours (from black to white).

The difference image 6.13 was compared with the image showing changes in greenness and brightness. The difference image appeared to be as useful as the other image and rather more desirable because of the high degree of interpretability associated with it. Therefore, this image can be used as a guide to where changes have occurred.

Changes in greenness and brightness were also analyzed from the difference image. Figure 6.14 shows the scatter diagram where

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Figure 6.13 : Difference image (1984-1980) for the representative study area.

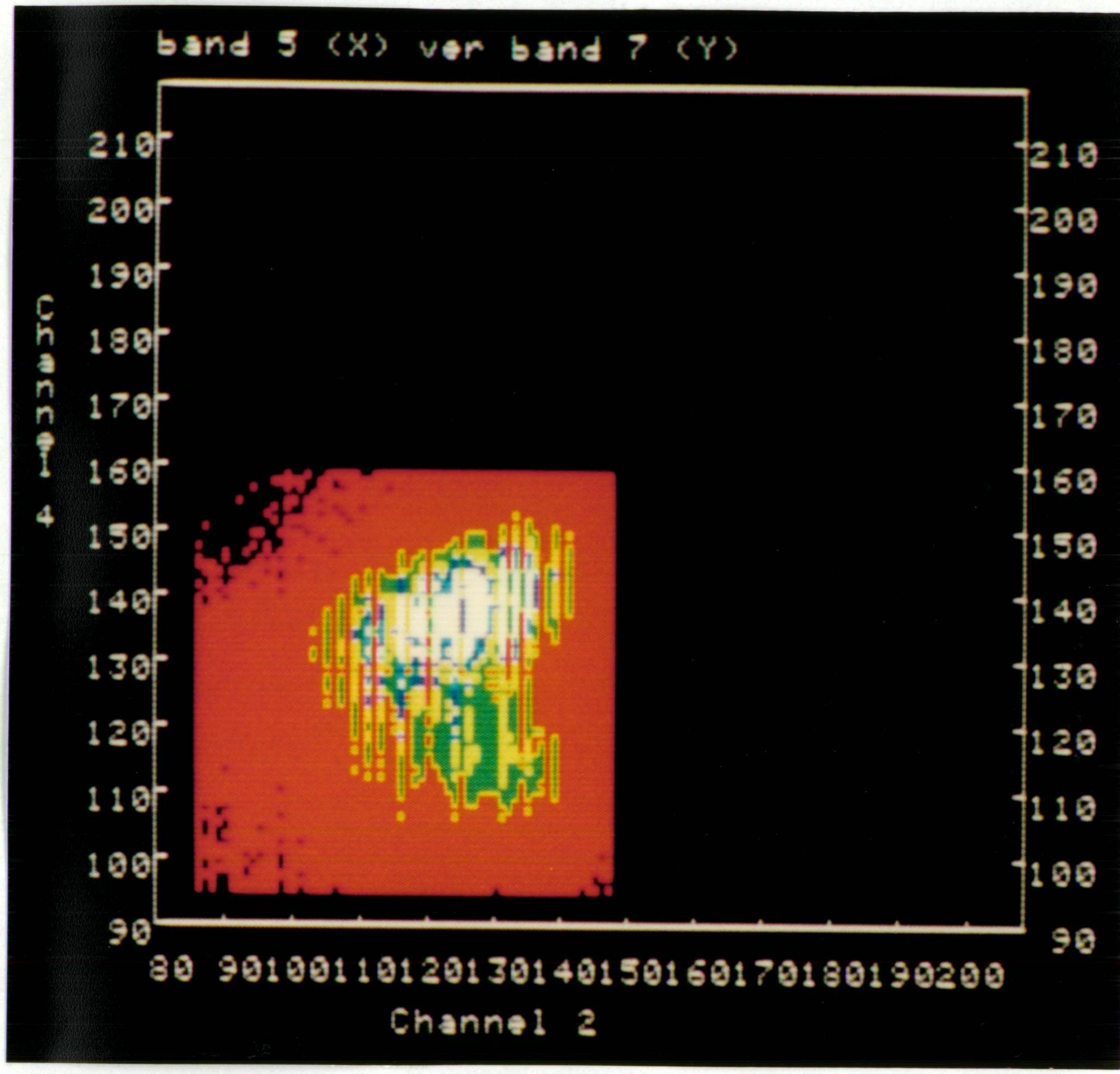

Figure 6.14 : Scatterplot of band 5 (X) against band 7 (Y) of the difference image.

band 5 of the difference image have been cross plotted against band 7. Assuming that greenness is related to only a high reflection in the infrared band and low reflection in the red band whilst brightness is characterized by high reflection in all bands:

$$\begin{aligned} \text{Greeness (G)} &= \text{Band 7} - \text{Band 5 and} \\ \text{Brightness (B)} &= \text{Band 7} + \text{Band 5} \end{aligned} \qquad (6.5)$$

therefore, the change in brightness $\triangle$ B (1984-1980) and the change in greenness $\triangle$ G (1984-1980) can be written as:

$$\begin{aligned} \triangle B &= [\text{ Band } 7_{84} - \text{Band } 7_{80} \text{] } + \text{ [Band } 5_{84} - \text{Band } 5_{80} \text{]} \\ \triangle G &= [\underbrace{\text{ Band } 7_{84} - \text{Band } 7_{80}}_{a} \text{] } - \text{ [} \underbrace{\text{Band } 5_{84} - \text{Band } 5_{80}}_{b} \text{]} \end{aligned} \qquad (6.6)$$

term 2 dominates for changes in bare surfaces, therefore increasing $\triangle$ B. Term 1, however is dominated for change occurring in vegetated areas. Thus in Figure 6.14, positive changes in greenness (increase in vegetation) is shown as a high incidence of pixels (white colour) above the 1=1 line. Conversely, positive changes in brightness (increasing bare surfaces) is shown as a high incidence (green colour) below the 1=1 line.

6.5 CHANGE DETECTION APPROACH BASED ON TWO DATE CLASSIFICATIONS

Post classification comparison is the most commonly reported technique for classification based change detection (Weismiller, et al., 1977; Rubec and Thie, 1978; Wickware and Howarth, 1981; Burns and Joyce, 1982; and Likens and Maw, 1982).

This method involves independent classification by pattern recognition techniques of two images of the same area, taken at two different time periods. The comparator is simply a processor that compares the two classification maps using class pairs specified by the analyst in the form of themes and produces a map highlighting the nature, location and amount of transitions. Here, the analyst defines the derived change classes rather than spectrally identifying the change classes using pattern recognition techniques. In this technique, as pointed out by Weismiller (1977), by properly coding the classification results for times t_1 and t_2, the analyst can produce change maps which show a complete matrix of changes. Also, selective grouping of classification results allows the analyst to observe particular subsets of change that may be of interest.

Generally, it is observed that this technique provides the analyst with a reasonable method for identifying both the change and the nature of the change. However, in the post classification change detection technique, the accuracy of the results depends on the individual accuracy level of the two different classifications. Given a random distribution of errors within each classification, the error in the detection of correct "from-to" change combinations would tend toward the sum of the errors of the two classifications. This results mainly from the random distribution of errors in the two classifications and errors caused by misregistration of the two images. In the operational use of this technique, Wickware and Howarth (1981) cautioned that the data should also be analysed to take into account phenological change in vegetation, atmospheric and sun angle influences.

In this thesis, the procedure followed for detecting temporal changes between two different seasons and different time period from Landsat images is outlined in Figure 6.15. The images from the two dates were geometrically corrected and independently classified using a log ratio model (For classification details see Chapter 5). For monitoring temporal changes, it is essential that the logical land cover types in the two classifications should be the same. In this project, 12 broad land cover types were selected so that direct comparison of the two scenes could be made. Comparisons were made not only for the Scottsdale district as a whole but for each of the forest blocks separately. Total area in pixels for each land cover class and for the two classifications is given in Tables 6.3 and 6.4. Actual and the percentage change in area between the two dates was then calculated which is given in Table 6.5.

6.5.1 INTERPETATION OF CHANGES BETWEEN IMAGES AND ITS APPLICATION IN NORTH EAST TASMANIA

In Table 6.5, using 1980 as a base time period, a seventy one percent increase in pine plantation area was observed. This reflects the Tasmanian Forestry Commission's recent policy of growing large exotic softwood plantation on Crown land to meet rising needs for softwood in the state. Total area under rainforest remained unchanged and this is most likely due to the ban imposed on rainforest logging in the area. A four percent increase in mixed forest (wet sclerophyll forest with rainforest understorey) was surprising. This increase was most probably

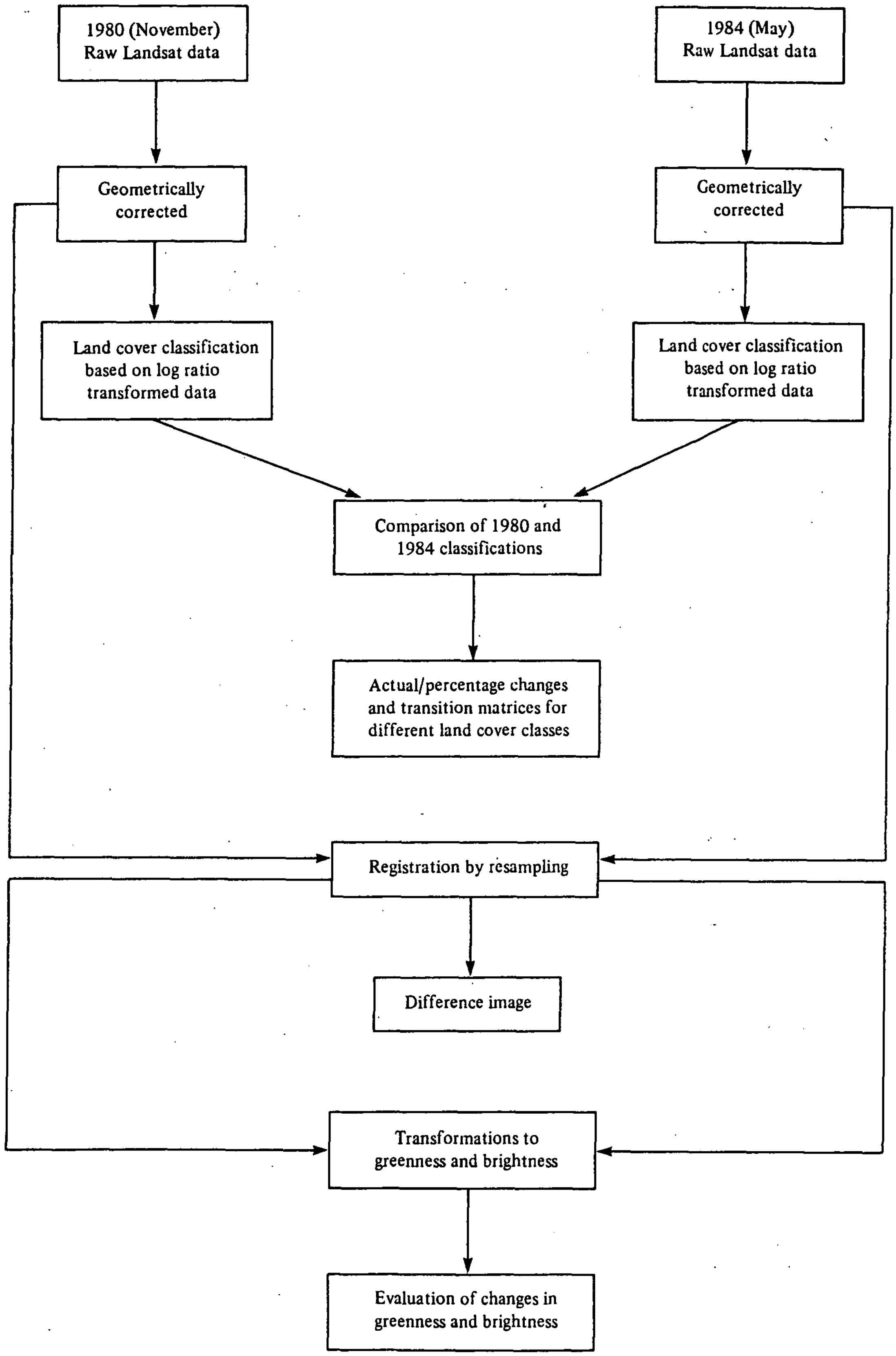

Figure 6.15 : Flow chart for change detection analysis.

Table 6.3

Total area in pixels (by forest block) - 1980

Cover types/F. blocks	1	2	3	4	5	6	7	8	9	10	11	Total
Pine plantation					1161		627		227	2181	3058	7254
Rainforest				2771	5196	11196	1061	2472			48	22744
Mixed forest				5691	7108	8133	5199	5660				31791
Wet sclerophyll forest	3610			23830	38081	44674	46502	16022	8801	25500	37212	244232
Dry sclerophyll forest	48113	83236	64693	6886			8957			14380	24803	251068
Agricultural/pasture land	23541	36554	4924	1429	7609	28588	40749	1843	1357	12956	34574	194124
Grassland	2571	3158	1270	655	1295	5436	2114	4963	1858	3174	4553	31047
Coastal heath/patchy woodland	1178	3835	1913									6926
Bare soil, burnt areas, p. fields	2613	8576	3023	122	430	772	2483	392	63	1220	2780	22474
Urban areas and farm buildings	163	925	29		1	63	491	2	3	96	190	1963
Sand dunes and tin mines	2225	367	1826									4418
Column totals	84014	136651	77678	41384	60881	98862	108183	31354	12309	59507	107218	818041

Table 6.4

Total area in pixels (by forest block) - 1984

Cover types/F. blocks	1	2	3	4	5	6	7	8	9	10	11	Total
Pine plantation					5459		7042		1067	5514	5740	24822
Rainforest				2738	5661	10490	1193	2672			45	22799
Mixed forest				5120	7252	7900	7749	4946				32967
Wet sclerophyll forest	3545			24619	32644	45916	37110	14456	7045	31201	32565	229101
Dry sclerophyll forest	41368	73889	60143	5176			16167			8189	27780	232712
Agricultural/pasture land	28522	45423	9961	2174	6972	27857	33231	3043	2581	10080	31888	201732
Grassland	2680	4218	1484	1085	1756	5301	2666	5281	1102	3297	6693	35563
Coastal heath/patchy woodland	980	2848	1685									5513
Bare soil, burnt areas, p. fields	1290	4021	1078	332	1029	1087	1388	542	315	834	1612	13528
Urban areas and farm buildings	2093	2848	1150	76	48	171	975	155	102	177	433	8228
Sand dunes and tin mines	2006	242	1521									3769
Dieback	1530	3164	656	64	60	140	660	259	97	215	462	7307
Column totals	84014	136653	77678	41384	60881	98862	108181	31354	12309	59507	107218	818041

Table 6.5

Overtime land cover changes

Land cover classes	Total number of pixels (1980)	Total number of pixels (1984)	Actual area changed	% change
Pine plantation	7254	24822	+17568	+70.77
Rainforest	22744	22799	+55	+0.24
Mixed forest	31791	32967	+1176	+3.56
Wet sclerophyll forest	244232	229101	-15131	-6.60
Dry sclerophyll forest	251068	232712	-18356	-7.88
Agricultural/pasture land	194124	201732	+7608	+3.77
Grassland	31047	35563	+4516	+12.69
Coastal heath/patchy woodland	6926	5513	-1413	-25.63
Bare soil, burnt areas, p. fields	22474	13528	-8946	-66.12
Urban areas and farm buildings	1963	8228	+6265	+76.14
Sand dunes and tin mines	4418	3769	-649	-17.21
Dieback	-	7307	-	-

because of the ease of mixed forest identification on the winter scene compared to the summer scene and therefore, not an actual change. During 1984, agricultural and pasture land also showed an increase of 3.7 percent compared to its total area in 1980. An increase in pasture land at the expense of sclerophyll forest was also reported by Kirkpatrick and Dickinson (1982).

The estimated area of grassland showed an increase of 13 percent whilst a decrease of 66 percent was observed for bare soil and fire burnt areas. These results are most likely firstly, due to the seasonal effect (winter versus summer image) and secondly, because of the excessive rainfall (see Figure 4.4) in the district. Lower winter temperature and excessive rainfall during the preceding month (April) for which 1984 Landsat scene was recorded, lead to an increase in soil moisture contents which caused emergence of grasses in bare soil and fire burnt areas.

Erroneous results were observed for urban areas. As discussed in Chapter 5, this was mainly attributable to the inability of Landsat to distinguish between coastal heath and urban areas in the study area so that changes in this class can be quite random.

The Department of Lands, Parks and Wildlife have been attempting to grow grasses on sand dunes as means of arresting their inward movement. This action was most probably responsible for the 17.21 percent decrease in sand dune areas depicted in Table 6.5. As mentioned earlier, it was not possible to estimate changes in the dieback class since it occurred mostly along the northern coast and this section was not available in the 1980 image.

6.5.2 TEMPORAL TRANSITION MATRICES

To fully analyze the temporal changes summarized in Table 6.5, we need to consider the complete temporal transition matrix between the two years. A temporal transition matrix describes the sequence or probable paths for a land cover type which may change from one type to another over a sequence of dates. In this project, a complete change matrix was obtained by cross tabulating 11 broad land cover classes for the two classifications. Sources of change in different land cover types highlighted in Table 6.5 can be traced from the change matrix shown in Table 6.6. In this table, the diagonal values represent unchanged areas whereas changed areas are depicted by off diagonal values. From column one of Table 6.6, it can be seen that the 71 percent increase in pine plantation between 1980 and 1984 is coming from many previous land uses. In descending order, sclerophyll forest, agricultural/pasture land, grassland and bare and burnt areas contributed the most. Similarly, the increase in agricultural/pasture land can be traced and is attributable to logging in wet and dry sclerophyll forest. In the case of grassland, the 12.69 percent increase is mainly coming from sclerophyll forest. As discussed earlier, this is probably due to the excessive rainfall in 1984 which lead to the increase of grassland especially in low to medium dense sclerophyll forest. Partly, this may also be attributed to the increase in grasses in barish agricultural/pasture land as well as in barish areas.

As expected, urban areas and heath land showed peculiar results. This is mainly because of the spectral overlap between

Table 6.6

Complete transition matrix

1984

Land cover		PP 1	RF 2	MF 3	WS 4	DS 5	AP 6	GL 7	CH 8	BP 9	UA 10	SD 11	TOTAL 12
PP	1	5445.	144.	148.	817.	228.	306.	119.	0.	45.	2.	0.	7254.
RF	2	948.	20215.	750.	232.	111.	88.	311.	0.	89.	0.	0.	22744.
MF	3	1087.	978.	27225.	803.	306.	350.	891.	0.	148.	3.	0.	31791.
WS	4	4063.	630.	1772.	205283.	19147.	10306.	2626.	32.	158.	215.	0.	244232.
DS	5	6716.	204.	801.	12552.	206714.	11047.	9323.	503.	1186.	1798.	224.	251068.
AP	6	2751.	97.	1755.	4428.	10866.	168664.	3152.	499.	7.	1863.	42.	194124.
GL	7	2530.	496.	235.	3545.	1289.	4250.	17949.	200.	395.	156.	2.	31047.
CH	8	0.	0.	174.	21.	78.	356.	155.	3291.	1387.	1429.	35.	6926.
BP	9	1264.	30.	86.	1339.	598.	6020.	955.	330.	9484.	1509.	859.	22474.
UA	10	18.	5.	21.	81.	33.	106.	62.	646.	378.	567.	46.	1963.
SD	11	0.	0.	0.	0.	651.	239.	18.	12.	251.	686.	2561.	4418.
	12	24822.	22799.	32967.	229101.	240021.	201732.	35561.	5513.	13528.	8228.	3769.	818041.

these two classes in the study area. To overcome this problem, as discussed earlier, there is either a need to analyze sequential Landsat images or to analyze high resolution data such as Landsat Thematic Mapper or SPOT imagery.

6.5.3 GENERALIZED TIME SERIES OF CHANGE

As information is built up in a consistent framework over time, the simple two data comparisons as demonstrated above will naturally lead into the generation of more generalized sequences of transition. Some generalized examples (Kirkpatrick, personal communication) applicable to the north eastern region of Tasmania are highlighted in Table 6.7. In this table for example, two successive fires in a wet sclerophyll forest may convert it into understorey type forest mostly consisting of bracken or fern trees. In the absence of subsequent fires, this area may develop into shrubland or may be converted back into wet sclerophyll forest by replanting the eucalyptus seedlings (case A). Similarly, as pointed out by Ellis (1985) in those rainforest areas that have not suffered appreciable fire damage for 200 years or more, shrubs such as *Acacia* or *Leptospermum propagules* are unlikely to to be present. In this case a fire that kills the rainforest induces grassland and over time, grassland may convert into a shrubland dominated by *Leptospermum* or rainforest shrubs. On such areas, rainforest may establish again once *Leptospermum* reduces or eliminates the grassland (case B).

As these examples show, the study of temporal transitions over a number of years will provide a framework for ecological studies and studies of succession. In principal, the acquisition

Table 6.7

Some probable vegetation transition paths in north east Tasmania

A: Wet sclerophyll → Undrstorey (bracken and fern) → Shrubs → Wet sclerophyll

B: Rainforest → Grassland → Shrubland → Rainforest

C: Eucalyptus → open understorey → Wet sclerophyll understorey → Rainforest → Rainforest understorey

D: Eucalyptus → Understorey (scrub) → Pasture → Agricultural land

E: Coastal heath → Woodland → Coastal heath

F: Coastal heath → Woodland → Pasture/Agricultural land

G: Eucalyptus → Scrub → Pine plantation → clearing → Eucalyptus or Pine plantation

H: Pasture → Agricultural land → Eucalyptus or pine plantation and direct tabulation of this information is an extension of the work reported in this thesis.

6.6 CLASSIFICATION METHOD IN A GIS CONTEXT

These sequential changes in various land cover types can be monitored by working in a GIS environment. This can be achieved initially by detailed land cover classification of an image pertinent to some base time period t_1 and then by spectrally transferring the base time period classification to the later images. Spectral as well as actual changes in different land cover types can then be traced by forming a residual image by subtracting the time t_2 classified image from its raw data.

In this project, 1980 was used as a base image and its classification channel was spectrally transferred to the 1984 image by using the mSPTRN program. The generated residual image (Figure 6.16) highlights those areas where actual changes occurred since base time t_1. As can be observed from Figure 6.16, an increase in vegetation is depicted by a pink colour (in pasture and agricultural land), deep red (in sclerophyll forest areas) and bright red (in pine plantation areas), whereas, a decrease in vegetation is depicted by a cyan colour. The spectral changes due to the different seasons of the two images are distinctly apparent in high relief areas where the shadowing effect is depicted by a brownish red colour.

The major advantage of this approach is its consistency in land cover classification. Moreover, it is time and cost effective. This is because of the fact that it allows enumeration

Figure 6.16 : Residual image for the representative study area. It has been generated from the 1984 raw data minus base image based 1984 classified image .

of the extent of changes by classifying and labelling the residual image only. Therefore, the location and the extent of changes can be monitored more frequently and quickly. Following a generalized time series change approach as discussed in section 6.5.3, transition matrices can also be constructed to monitor the nature of shifts pertinent to temporal changes in various land cover classes.

However, together with such transitions sequences, it becomes extremely important to assess the accuracy of the results. The accuracy of class transitions is related to, but not the same as, that of classification at a single date. Clearly, the change between two dates of two very poorly resolved classes will be very low in accuracy, will disturb other transitions data and could lead to nonsensical conclusions. In this study an error analysis was performed for the 12 land cover types by using the following formula:

$$\text{Percentage error} = \left(1 - \sum (P_{ij})^2\right) \times 100 \qquad (6.7)$$

where P_{ij} is the probability that a pixel which in reality belongs to a class C_i, is labelled as class C_j in a Landsat data based classification. P_{ij} values shown in Table 6.8 are calculated by using the normalized error matrix (Table 5.7).

From this analysis, it can be implied that given no change in actual land cover, some variation associated with classification uncertainty may be expected. This is mainly due to spectral overlap between the classes. The magnitude of error associated with 12 land cover classes is shown in Table 6.8.

Table 6.8

Percentage error associated with the classification of the various land cover classes

Land cover classes with symbol		(PP)	(RF)	(MF)	(WS)	(DS)	(AP)	(GL)	(CH)	(DB)	(BP)	(UA)	(SD)	% error
Pine plantation	(PP)	0.735	0.075		0.151						0.039			18.56
Rainforest	(RF)		0.871	0.129										5.77
Mixed forest	(MF)		0.097	0.772	0.131									14.25
Wet sclerophyll forest	(WS)	0.008	0.005	0.011	0.963		0.012							0.52
Dry sclerophyll forest	(DS)			0.005	0.058	0.928		0.009	0.001					1.83
Agricultural/pasture land	(AP)	0.004			0.023	0.042	0.927		0.001			0.002		1.98
Grassland	(GL)						0.129	0.836					0.034	8.02
Coastal heath	(CH)						0.428		0.377	0.160		0.035		41.96
Dieback	(DB)					0.242			0.016	0.674	0.068			23.25
Bare soil, ploughed fields	(BP)						0.298				0.678	0.024		20.33
Urban areas, farm buildings	(UA)						0.501		0.053			0.446		29.94
Sand dunes, tin mines	(SD)											0.066	0.934	1.63
Column total		0.747	1.049	0.917	1.326	1.211	2.296	0.845	0.448	0.834	0.785	0.573	0.968	

Percent error is low for most of the cover classes. However, for the coastal heath and urban areas, it is relatively high. This can be attributed to the previously discussed inability of the Landsat data to map these classes.

While not providing error bars for the change estimates, this analysis does highlight to changes which can be used with most confidence. The complete analysis of error and error estimates for multi-date sequences of classifications is a study which will need far more attention as data is built up in a GIS context.

CHAPTER 7

SUMMARY AND CONCLUSIONS

This study has developed a methodology for mapping and monitoring forest resources using Landsat data with particular emphasis on the conditions encountered in Tasmania, Australia. The need for this study stems from limitations in present inventory techniques when applied at the regional scale. At this level, traditional survey methods are variable in quality and quantity, are not continuous in time or space and are costly to apply. In the State of Tasmania in particular, survey efforts have been directed towards the use of photo-interpretation to produce maps for planning and management purposes. This is an expensive exercise, not only to develop for the state as a whole, but also to update at regular intervals. In addition, there is little information on private forest in private lands because there are no regular surveys being conducted in these areas. Against this background it was decided to examine the feasibility of using remotely sensed satellite data characterized by regional coverage at regular intervals. In particular, the thesis objectives were to provide a regional vegetation map, monitor temporal changes in vegetation and to demonstrate the use of Landsat digital data as an input to a Geographic Information System for forestry purposes.

Local studies are needed to determine the applicability of techniques developed over broad-leaved northern hemisphere forests for evaluation of Landsat data to Australian forest environments which are characterized by sclerophyllous vegetation. As yet there have been few studies of this kind conducted in Australia and none in the State of Tasmania.

The Scottsdale forestry district, situated in north eastern Tasmania was selected as the study site because it includes most of the vegetation types, and has a complex topography typical of the State. Two Landsat computer compatible tapes (1980, 1984) of the study area were selected for the analysis. All data processing was performed using the BRIAN and microBRIAN image processing packages, at CSIRO Division of Water Resources Research, Canberra.

The results of the analysis specific to the data set, study area and framework for analysis of this thesis are summarized as follows:

1. In response to the problem of varying illumination created by the topography of the area, a radiance model was developed which used the logarithms of the band ratios as well as illumination information. The intention of this approach was to define classes on the basis of both spectral similarity and illumination. In this case illumination means basically sunlit versus shadowed. The classification based on the radiance model resulted in 168 and 188 spectral classes for the 1980 and 1984 scenes respectively.

2. Aggregation of above spectral classes was performed by analyzing their spectral similarity and spatial separation. This was accompalished using canonical variate analysis and with the aid of Minimum Spanning

Trees. As a result, 28 (1980) and 29 (1984) land cover classes were obtained. These groups were assigned meaningful labels in terms of actual land cover classes. The labelling procedure used three important parameters in the Landsat scene, namely, spectral, landform and image patterns. The labelling of spectral classes was performed with the help of existing maps of vegetation type, photo-interpretation maps prepared by the Tasmanian Forestry Commission and consultation with field staff who had a detailed knowledge of the study area. Detailed land cover classes were further aggregated into 12 broad land cover classes.

3. A total of 373 test sites distributed throughout the study area were used to determine the accuracy of the classification for the 12 land cover classes. An overall accuracy level of 90 percent was obtained. For individual land cover classes the level of accuracy ranged between 38 and 96 percent.

Knowledge of seasonal effects was critical for identification of some land cover classes. For example, button grass, urban areas and bare soil were more easily identifiable on the summer scene as compared to the winter scene. On the other hand rainforest was comparatively easy to identify on the winter scene.

Spectral similarity was observed between different land cover classes. For example sand dunes and tin mines had very similar spectral responses. Old pine plantations overlapped spectrally with wet sclerophyll forest. Similarly, rainforest and young pine plantation also spectrally overlapped with each other.

To resolve the problem of spectral similarity between different land cover classes, forest block boundaries were merged with the Landsat data. This enabled overlapped classes to be labelled differently in different management zones, keeping in mind the a-priori information about the spatial distribution of various land cover classes. As a result, an increase in the overall accuracy level for the spectrally overlapped classes was achieved.

4. Principal Component Analysis and Image differencing highlighted the spectral changes between the two images taken in two different years. Actual and percentage change between 12 broad land cover classes were obtained by direct comparison of the classifications for the two dates. Land cover changes over time were enumerated not only for the Scottsdale district as a whole but for each forest block separately.

5. Analysis of the two images revealed a significant increase in pine plantation and a decrease in wet and dry sclerophyll forest. A decrease in sand dunes and coastal heath, and an increase in pasture and agricultural land were also observed. Rainforest areas showed no change over time. Erroneous results were observed for urban areas mainly due to spectral overlap with coastal heath.

6. In order to simulate an operational Geographic Information System (GIS) using remotely sensed data as an input, a conceptual GIS implemented on a micro-computer based image processing system was developed for forest resources in Tasmania. In this system, Landsat MSS, digital terrain and administrative boundaries data were integrated to provide a framework for analysis. These data layers of different projection and spatial resolution were resampled to a two second grid and were georeferenced into a common spatially congruent system of latitude and longitude coordinates.

7. The digital terrain data were also computer processed to ensure compatability with the information system, and to calculate slope, aspect and insolation information. All these data were calculated from the processed elevation values which were obtained from the digitized 1: 100 000 topographic maps. Therefore, it formed an important segment of the forest information system developed in this thesis.

From the above summarized research it may be concluded that by using the model developed in this thesis, it is possible to map broad land cover classes accurately in areas of complex topography, to monitor land cover changes and to incorporate the resulting information into a GIS. Landsat with its 80 meter pixel size, cannot provide the detailed level of information currently available from aerial photographs. However, it does provide a broader level of resource information with a high degree of spatial accuracy. Therefore, this technique could be applied successfully to provide, in a cost effective and rapid manner a broad scale classification for the entire State of Tasmania as well as similar areas throughout the world. This task would involve the inclusion of area specific land cover types and more use of multi-temporal images to further improve the accuracy of classification.

Although there are many applications of a Landsat based GIS to the Tasmanian environment, it was not the purpose of this thesis to describe them in detail. Nevertheless there are two specific applications resulting from this work. Firstly, sequential changes in various land cover types can be monitored regularly within the framework of a GIS. If a base time period classification is stored in a GIS environment, then changes at a later time can be evaluated by comparison with the base classification. It is then possible to concentrate on areas of change or on poorly classified areas instead of reclassifying the entire scene. This approach would indicate the location and type of change as well as associated environmental and social variables such as topography, climate, soil type, administrative boundaries etc.

Multi-temporal images within the framework of a GIS could provide information on over time growth associated with cover types of interest. Overseas researchers have shown that this type of information can be associated with yield tables in order to infer timber volume for various forest types. A desirable level of accuracy may be achieved in the analysis by stratifying the areas of interest into homogeneous geographic regions.

It is a costly exercise to establish an operational GIS which incorporates remotely sensed data. It involves the purchase of an image processing system, digitizing equipment and associated hardware and software. A fully developed operational system will also require trained manpower in order to extract the information on a regular basis. Despite the initial cost however, the system is economical in the long run because it provides resource related information at a fractional cost of traditional techniques. In addition, it is likely that such a versatile system would make possible the implementation of a range of projects which would not be normally possible or applicable.

The methodology developed in this thesis is applicable to satellite systems with increased spatial and spectral resolution. In particular, data from the Landsat Thematic Mapper (30 meter pixel) and the SPOT (20 meter pixel) satellite create new and exciting possibilities for further work in remote sensing of forest resources. The increased spatial resolution of these satellites not only increases the potential for visual interpretation of the images, but as well should provide an improvement in the accuracy and detail of information provided by the classification techniques described in this thesis.

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APPENDIX A1.0

SATELLITE REMOTE SENSING

A1.1 DEVELOPMENT OF SATELLITE REMOTE SENSING TECHNOLOGY

The term "Remote Sensing" is used to describe the acquisition of information about specific objects by an information gathering device at some distance from the objects under investigation. The best known form of remote sensing is aerial photography. This was first used extensively in Europe during the First World War. Small aircraft and balloons carried photographers on reconnaissance flights over enemy lines. The panoramic view provided valuable information for the effective deployment of men, supplies and artillery. The development of specialized cameras for aerial work and sophisticated processing of data enabled detailed and accurate results to be provided more quickly and cheaply than ground based techniques. During and after the second world war, radar and infrared radiation technologies were used to widen the range of information available through aerial photography. However, in the 1960's and 70's the United States space program introduced a completely new dimension to remote sensing. Data provided by satellites, namely Apollo, Skylab Missions and the Landsat satellites could be usefully applied to a wide range of disciplines (Academy of Science, 1974).

A1.2 HISTORY OF THE LANDSAT PROGRAM

Since July 1972, five Landsat satellites have been launched. The first three in the series were similar in configuration and in the nature of the data that were obtained. An additional instrument, the Thematic Mapper (TM) was introduced in Landsat 4 and 5. The primary objective of the earlier satellites was to test the feasibility of collecting useful data on earth resources from approximately 920 kilometers above the earth surface. Their success gave impetus to the development of later and improved satellites. The latest in the series, Landsat 5, was launched on March 1, 1984.

The two often quoted limitations of the earlier Landsat series are their modest spatial resolution and the lack of correspondence between the spectral channels and the geo-botanical absorption bands of interest in many applications. The TM instrument on the later Landsat satellites 4 and 5 (see Figure A1.1) was designed to alleviate these problems. These satellites continue to employ the same four MSS bands or channels (which detect electromagnetic energy in the wavelength range 0.5 micron to 1.1 micron) of the earlier 3 satellites. Additionally their TM sensors record information in seven channels in the electromagnetic spectrum ranging from 0.45 to 12.60 microns. The TM is intended for use in providing unique tone signatures for various kinds of resource related features, thus facilitating the production of thematic maps pertaining to those categories. The resolution of TM data is 30 meters compared to 80 meters MSS resolution. (For further details the reader is referred to the Manual of Remote Sensing, 1983).

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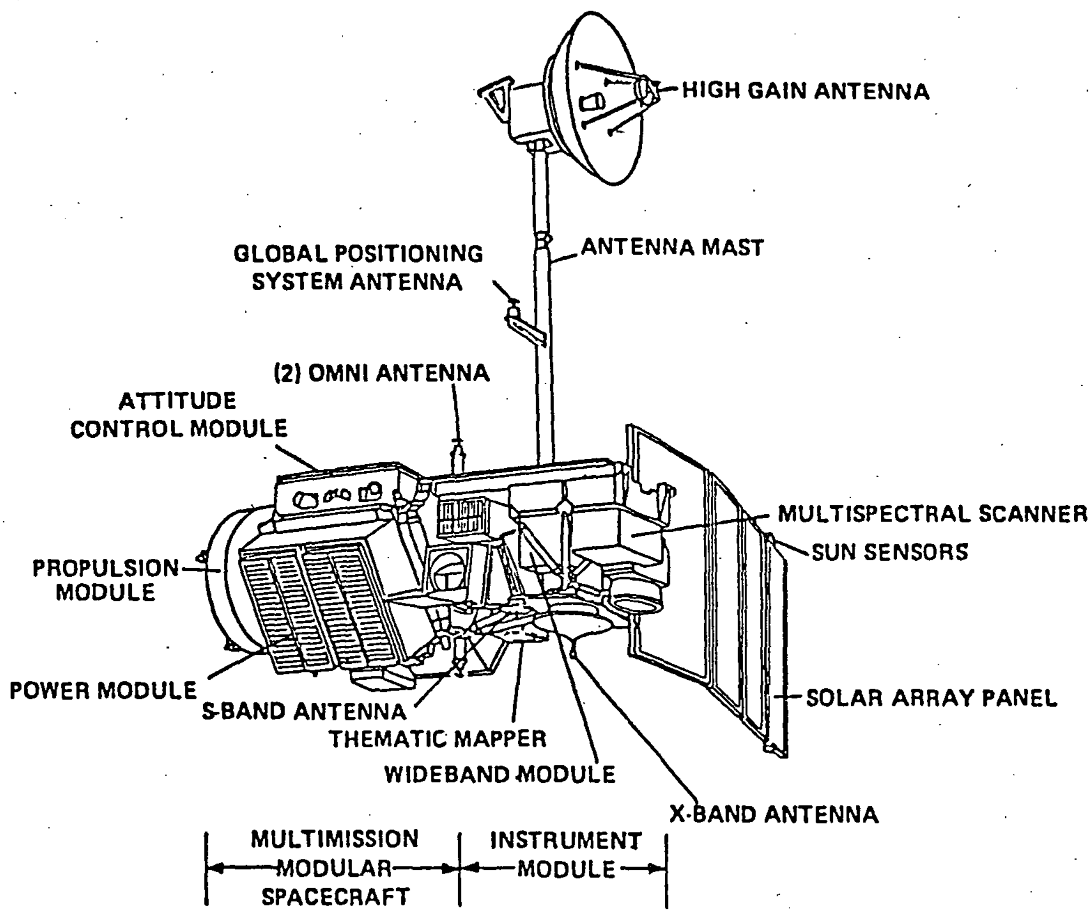

Figure A1.1 : Observatory configuration of Landsats 4 and 5.
(Source : Manual of remote sensing, 1983).

A1.3 THE LANDSAT SYSTEM IN GENERAL

A1.3.1 ORBIT RELATED CHARACTERISTICS

The Landsat satellites have been launched at two altitudes. Landsats 1, 2 and 3 had an approximate altitude of 905 kilometers, whilst Landsat 4 and 5 have an altitude of 705 kilometers. Each satellite operates in a circular near polar orbit. Landsat 1 to 3 completed each orbit in 103 minutes (14 times a day) and covered the earth every 18 days, whilst Landsat 4 and 5 complete each orbit in 99 minutes (14.5 orbits per day) and cover the entire earth every 16 days.

A Landsat satellite scans a width of 185 km along its flight line. The Landsat 1-3 orbital coverage creeps westward by one orbit swath each day providing adjacent coverage on consecutive days, whereas adjacent coverage occurs every seven or nine days (to the west and east respectively) with Landsat 4 and 5. Landsats 1 and 3 had a half-cycle relationship with Landsat 2. That is, their orbits are separated in time by nine days to essentially double the data acquisition rate over a given area when two satellites are operational at the same time. Similarly, Landsat 4 has a half cycle relationship with Landsat 5, their orbits being eight days apart. Landsat 5 is the current operational satellite.

For Landsats 1-3, the distance between adjacent orbit paths at the equator is 159 km. This results in a swath overlap of 14 percent at the equator, for the nominal swath width of 185 km, with greater amounts of overlap at higher altitudes. Landsats 4 and 5 have lesser amounts of overlap, that is, seven percent at the equator on their adjacent paths. (Malila and Anderson, 1986). The essential working unit of Landsat data is a scene which has dimensions 185 km x 185 km. Image acquisition, which is from north to south during each daily sequence, occurs at the same local time of the day since the satellite is in a sun-synchronous orbit. It requires about 45 minutes for the satellite to travel from latitude 80 degree north to latitude 80 degree south, maintaining a constant sun time (not local zone time) of 9.30 am at the equator. This allows the sensing system to view each part of the world at the same time of day and gives maximum consistency of lighting conditions. The satellites return to the same location, at the same sun time, every 16 days.

A1.3.2 IMAGING SYSTEM

The earlier Landsat satellites consisted of two data collection systems: the multispectral scanners (MSS) and the return beam vidicon (RBV). Also included were a data collection system (DCS) relay antenna and two video recorders. Because of the technical problems with the RBV system, Landsats 4 and 5 did not carry a RBV system or onboard recording facilities. However, these satellites carried an additional TM scanner. The MSS and TM consist of four and seven spectral radiometers respectively. These scan the surface of the earth and register the intensity of energy reflected by features and objects on earth. For detailed information see Douglas (1980) and Academy of Science (1974).

Every object on earth reflects, absorbs, transmits or emits electromagnetic energy at a given wavelength. If we define reflectance as the ratio of the radiation flux leaving the object to the incoming irradiance from the sun, then for any particular object we can plot the reflectance against wavelength. The physical properties of the object itself establish how much of the solar radiation is reflected at each wavelength. The reflected radiance with its distinct spectral or wavelength distribution for each object (referred to as the spectral signature of the object) is detected by the MSS and TM sensors on the Landsat satellites. The spectral wavelength intervals detected by the scanning system on Landsat satellites is given in Table A1.1.

These spectral bands enable specific objects on the earth surface to be imaged with maximum contrast against their background, due to the particular spectral reflectance characteristics of the ground object. However, since the recorded radiation of any natural scene is influenced by many and varied factors, the analysis of reflectance and emission is a complex process (see Table A1.2).

The reflectance level in each of these spectral bands indicates something about the objects being sensed. The following pattern is obtained in an image in which brightness is proportional to spectral reflection:

Band 4-- water is lightest, vegetation is darker and bare areas such as roads or urban development appear bright

Band 5-- water is darker, vegetation is darkest and bare areas are bright

Table A1.1

Wavelength intervals recorded by Landsat Satellites

Data channel	System	Type of radiation	Wavelength (microns)	Band or channel
1	MSS	Visible green	0.5-0.6	Band 4
2	MSS	Visible red	0.6-0.7	Band 5
3	MSS	Infrared IR	0.7-0.8	Band 6
4	MSS	Infrared IR	0.8-1.1	Band 7
1	TM	Visible blue	0.45-0.52	Channel 1
2	TM	Visible green	0.52-0.60	Channel 2
3	TM	Visible red	0.63-0.69	Channel 3
4	TM	Near infrared	0.76-0.90	Channel 4
5	TM	Middle infrared	1.55-1.75	Channel 5
6	TM	Middle infrared	10.4-12.60	Channel 6
7	TM	Thermal infrared	2.08-2.35	Channel 7

N.B Some authors interchange channels 6 and 7 in TM.

Source : (Manual of Remote Sensing, 1983)

Table A1.2

Sources of variation in multispectral signatures of vegetation
Illumination conditions
Illumination geometry (sun angle, clouds distribution)
Spectral distribution of radiation
Reflective and emissive properties
Spatial properties (geometric form, density of plants, and patterns of distribution)
Spectral properties (reflectance or colour)
Thermal properties (emittance and temperature)
Plant conditions
Maturity
Variety
Physiological conditions
Turgidity
Nutrient levels
Disease
Heat exchange processes
Atmospheric conditions
Absorption, scattering and emission by water vapours and aerosols

Source:- Polcyn et al. (1969)

Band 6-- water is darker again, vegetation is much brighter and bare areas are bright

Band 7-- water is darkest, vegetation is brightest and bare areas are bright

Because of this variation in spectral reflectance between different land covers, it is possible to use multispectral data to map the land cover and detect cover changes over time.

A1.3.3 THE MULTISPECTRAL SCANNER

The MSS system consists of four sets of six optical sensors. Each set is filtered to record light from a separate part of the spectrum. Imaging is accomplished by collecting light from the earth's surface on an oscillating mirror and passing this light through a telescopic system to the four filtered sets of optical fibers (Figure A1.2). Each of the selective filtering devices records information within a specific portion of the electromagnetic spectrum defined in units of wavelength. These are often described in terms of the nearest colour represented by that wavelength such as red band, green band etc.

As the satellite moves from north to south, it scans across its path from west to east. Each of these scans records six image lines. Along each line, the sensors measure the electromagnetic energy radiated by the earth's surface in four wavelength regions or bands (see Table A1.1). These measurements integrate the radiance of an area on the earth's surface which is called a "pixel". In Landsat MSS imagery, a pixel is approximately 80 m or about .45 hectares. An image is formed by detecting the

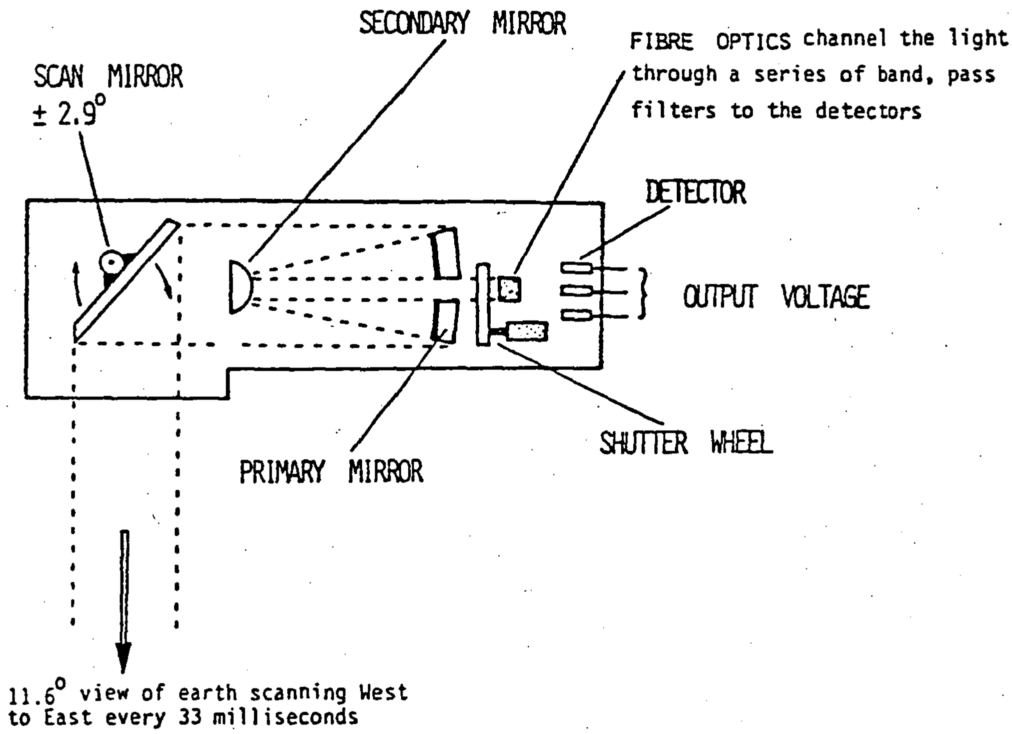

Figure A1.2 : Working mechanism of multispectral scanner.
(Source : Norwood *et al.*, 1972)

radiance of adjacent pixels along a line and adjacent lines along the satellite track, thus building up a grid of radiance measurements. A single square Landsat MSS image (185 x 185 km) is composed of 7.6 million pixels.

A single pixel may include a variety of land cover types, each of which radiate varying amounts of energy in different regions of the spectrum. The radiance detected for the pixel then is a combination of the radiances of its individual components. The composite radiance value depends on the properties of the pixel covered by, and the relative radiative intensity of, each component. A pixel which contains more than one cover type is referred to as a mixed pixel or "mixel". The area of a cover type relative to the area of a pixel determines the amount of mixing in an image. The pixel size in Landsat MSS imagery results in a fairly low level of mixing in large area, uniform cover types such as oceans, forests and deserts. However, cover types which vary more frequently over small areas, such as urban areas and mixed crop lands, render a higher degree of mixing in Landsat MSS pixels.

For each pixel, the composite radiance in each of the four wavelength bands is detected and then transmitted to the ground receiving stations. The radiance measurements are coded as integer values, in the range 0 to 255 (0 being minimum and 255 maximum detectable radiances), resulting in four values (one in each band) for each pixel in the image. For details of MSS system characteristics see Table A1.3.

Table A1.3

Characteristics of the Landsat Multispectral Scanner System

	Landsat 1-3	Landsat 4-5
Number of detectors	6	6
Altitude (km)	905	705
Nadir footprint of IFOV (m)	79 x 79	82 x 82
Scan angle (degrees)	$\pm$ 5.78	$\pm$ 7.46
Swath width (Km)	185	185
Ground sample spacing (m)		
- Scan direction	57	57
- Line to line	79	57
Radiometric resolution (Bits/Band telemetered)	6	6

Source:- Malila and Anderson (1986)

A1.4 THE LANDSAT GROUND SEGMENT

The Landsat MSS data is recorded by the Australian Centre for Remote Sensing (ACRES) at Alice Springs with the aid of a 9.14 metre steerable parabolic dish antenna and associated electronic equipment. This Data Acquisition Facility (DAF) tracks a spacecraft when it is within the range of the antenna. This provides coverage for all of continental Australia (see Figure A1.3). The satellite images are recorded in digital form on High Density Digital Tape (HDDT) and transferred daily for processing into computer compatible tape (CCT) format at the ACRES Data Processing Facility (DPF) in Canberra. The following processing options may be applied to the recorded data:

- sensor balance corrections
- decompression of the data
- calibration of input radiance
- contrast enhancement
- film gamma corrections
- non linear scan mirror velocity
- sensor offset
- panoramic distortion correction
- earth curvature correction
- earth rotation correction
- line length correction

The outputs of the recorded remotely sensed data available to the public are in the form of (CCT's) or paper prints. The paper prints are either black and white for individual bands or colour composite images (Division of National Mapping, 1986).

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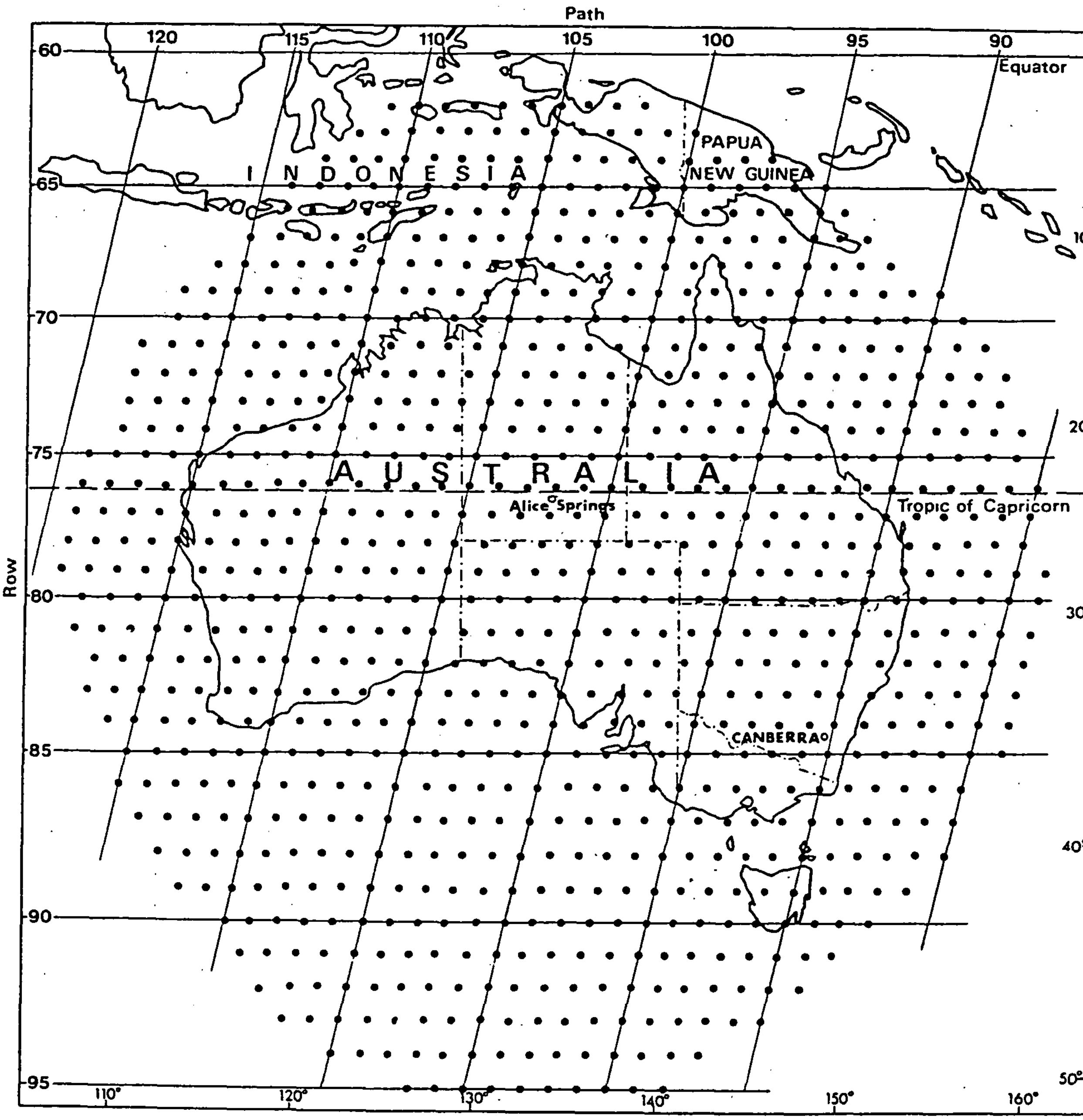

Figure A1.3 : Australian nominal scene centre for Landsat 4 and 5.
(Source : Jupp et al., 1985)

A1.5 DATA INTERPRETATION AND ANALYSIS

Valuable information can be extracted from Landsat imagery in a number of ways. These are listed below in order of increasing sophistication and cost.

1. Manual interpretation of standard photographic products using very simple, inexpensive instruments.
2. Manual interpretation aided by photographic enhancement and optical equipment
3. Digital analysis of the computer compatible tapes in a process of man-machine interaction to produce the desired computer output which, in turn, require further human interpretation and analysis.

The first and the simplest method requires skills of photo interpretation which are familiar to foresters, agriculturists or other resource scientists. This technique requires light tables and simple projecting equipment. The more experienced the analyst is in his subject and study area, the better the interpretation is likely to be.

The second method involves additional enhancement facilities to assist the interpreters. Such enhancements may also be used with special equipment such as a zoom transfer scope, colour additive viewer and microdensitometer. The zoom transfer scope enables data from enhanced images to be transferred to resource maps at different scales. Using a colour additive viewer, the investigator can view combinations of photographic positives and negatives of the individual spectral bands of a scene through separate colour filters, at different intensities. Densitometers measure the colour densities of either a composite colour reproduction or of each layer of colour by insertion of appropriate filters and may be used to quantify some aspects of visual image analysis. The photographic procedures used in this level of analysis include techniques for bringing out boundaries or edges of surface features, for superimposing several images taken on different dates, and for assigning different colours to specific image density ranges for better differentiation (National Academy of Sciences, 1977).

In digital analysis of Landsat data, a computer is used to perform the above operations as well as more advanced ones. In this operation the computer is programed either

1. To define spectral classes using ground data (supervised classification technique), or
2. To group the data from the Landsat scene into a given number of computer defined spectral classes (unsupervised technique or cluster analysis). These classes are then described using ancillary information.

A1.5.1 SUPERVISED CLASSIFICATION

The supervised technique assumes that the analyst has some knowledge of ground cover types in the study area. The analyst selects homogeneous training areas in the image which represent the cover classes of interest. These areas are interactively located in the image and their mean spectral values recorded as class seed values. The classification process then attempts to allocate each pixel in the image to one of these classes. Thus the supervised approach is heavily dependent upon the ability of the analyst to define spectrally separable informational classes. A crude classification will result and accuracy will suffer if the classes defined are not spectrally separable or the ground data are not fully representative of the classes. Hoffer et al. (1979) gave the following logical sequence of events for developing training statistics in a supervised classification :

1. Specify the classes of interest
2. Locate homogeneous training fields in each land cover class using ancillary data
3. Formulate the statistics for each land cover class
4. Evaluate the statistics and subdivide those spectral classes which are multimodal
5. Use these statistics to classify the area of interest
6. Evaluate the classification.

In order to run an accurate classification using the supervised approach, Ellis (1978) gave the following guidelines:

1. Classes must be as spectrally distinct from each other as possible.
2. Training fields should be as homogeneous as possible.
3. Bimodal (mixed) classes should be avoided.
4. Training should be representative of the entire area classified.
5. Training fields should be 40 acres in size or greater (approximately 36 pixels).

It should be noted that the training field size criteria wa suggested in relation to a shrubland classification. Training field size may vary according to the complexity of the study area. The more complex the area, the smaller the size of the training field, but the greater the number needed. Ellis found two common problems inherent in the supervised classification procedure:

1. The analyst does not identify and define important spectral classes, thereby confusing and decreasing the effectiveness of the classifier. Alternatively he may identify a land cover class that is not spectrally differentiable
2. Within an informational class, training sites selected d not adequately characterize that class.

A1.5.2 UNSUPERVISED CLASSIFICATION

The unsupervised technique uses the statistical properties of the images as the basis for classification. Multivariate clustering algorithms are used to assign pixels to spectral classes and generate new classes. Separability statistics for these classes are then used to determine their spectral proximity. If classes are inseparable, clustering is performed again with fewer classes to assure a maximum number of classes with low variance. After classification is complete, spectral classes are then identified using ancillary information available to the analyst, such as aerial photographs, photo-interpretation maps, vegetation type maps, topographic maps or ground checked areas.

In an unsupervised classification, the analyst must specify

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the number of spectral classes that are required. If too few classes are specified, they will have large variance and may be multimodal. If too many classes are specified, noise is introduced into the system and, more importantly, the analyst may have problems in identifying and explaining the large number of output classes.

The results of the digital analysis can be presented in a variety of visual forms, statistical tables, graphs, digital maps, histograms, map overlays, annotated images or thematic maps in which the landscape objects or features of interest are enhanced and often appropriately colored to define their locatio and extent.

APPENDIX A2.0

LEVEL I AND LEVEL II CLASSIFICATION

Although in the literature there are some differences in the definition of Level I and II land use/cover classes, the most generalized and widely accepted description was given by (Anderson et al. 1976). By reference to the Anderson system the type of class referred to in many papers discussed here can be compared consistently.

Level I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications and utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural areas
	23 Confined feeding Operations
	24 Other Agricultural Land

3 Range Land	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wet Land	61 Forested Wet Land
	62 Non-forested Wet Land
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Ground Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

APPENDIX A3.0

PREPROCESSING OF LANDSAT DATA

Landsat MSS data contains various radiometric errors which need to be corrected. These are mainly radiometric striping, bad data lines and atmospheric attenuation. Digital analysis usually begins with certain preprocessing steps which correct these problems. The corrections are described in more detail below:

A3.1 RADIOMETRIC STRIPING

The Landsat MSS system, which has six detectors for each of the four spectral bands, scans six lines of data with each oscillation of the sensor mirror. Each of these detectors has a slightly different response to the electromagnetic radiation reaching it. As a result the same intensity of incident radiation is not measured equally by the six detectors. This results in a series of lines which run horizontally across the image and is known as striping. This effect contributes to errors in computer aided classification and sometimes alters the spectral signature of the land use/cover classes.

In this project the data was radiometrically corrected by using the PEEK program of the BRIAN sofware (Jupp <u>et</u> <u>al</u>. 1984). The algorithm used in PEEK is based on the histogram modification technique which goes through a procedure in which a transformation is constructed such that the histograms of the channels after transformation match reference histograms. For further details see Kautsky <u>et</u> <u>al</u>. (1984); Horn <u>et</u> <u>al</u>. (1983) and Hummel (1975, 1977).

A3.2 STRETCHING OR COLOUR ENHANCEMENT

The main objective in image enhancement is to make the features of interest clearer and sharper than in the raw data. The standard way of displaying a Landsat image on a colour display is to use the radiance in any three bands as the intensity of colour on the blue, green and red guns. The colours then mix additively and produce a colour image. By interchanging the colours associated with different bands, images with different colour balance can be obtained making the features of interest in the image more prominent. A wide range of enhancement techniques are described in the literature (see for example Barrett and Curtis, 1976 and Lintz and Simonett, 1976). In this study the linear stretch enhancement technique offered in the BRIAN software was used.

In each spectral band the data occupy a range of radiance values which are coded during the recording and processing to a grey scale with 256 levels. This grey scale separates the data, so that each level of the scale represents a particular radiance level or colour intensity.

The histograms of the four bands contain different radiance values and have different minimum and maximum values on the possible scale of 0-255 grey levels. The technique rescales the data so that the minimum of each band is set to zero and the maximum value(that is, the 95 or 99 percent value, whichever is selected) is scaled to the 254 level (the value 255 is reserved for mask pixels in microBRIAN). As a result the actual data range in each channel can be spread over the full brightness range of the output device, thus sharpening and enhancing the image. For further details see Jupp _et_ _al_. (1984).

A3.3 ATMOSPHERIC EFFECT CORRECTION

Because Landsat "looks" through the atmosphere during imaging, the radiance values recorded are affected by atmospheric scattering. It has been reported by many researchers that the spatial and temporal variations in atmospheric haze can cause a decrease in the accuracy of the classification (Turner and Spencer, 1972; Potter and Mendlowitz, 1975; Ueno _et_ _al_. 1978; Dozier and Frew, 1981). A number of approaches (such as histogram minimum method, reflectance conversion of intercept term, regression of band 4,5 and 6 upon band 7, and measurement of path radiance during the Landsat overpass) have been reported in the literature (Chavez, 1975; Farnik, 1978; Ahren _et_ _al_. 1977; Lyon _et_ _al_. 1975; Honey _et_ _al_. 1974; Ballew, 1975; Abrams, 1978; Sorensen, 1979 and Dave, 1978).

In this study, an atmospheric path correction was calculated by using the covariance matrix method (Switzer, 1982). According to this technique the radiance measured by the sensors over terrain with undulating form has two components:

1. Radiance contributed by the surface in the field of view of the sensor; and
2. Radiance which does not originate from the surface within the field of view

The former is information and the latter is termed noise or atmospheric path radiance and noise. In model form, the measured radiance Y_{ij} for pixel i (as i runs over all pixels in the image) and in band j can be expressed as:

$$Y_{ij} = c_i X_j + d_j + n_{ij} \qquad (A3.1)$$

where

$c_i X_j$ - Information due to solar radiation reflected from the target

d_j - Atmospheric path radiance

n_{ij} - Unexplained noise

The term c_i is a multiplier which describes the effect of pixel topographic orientation with respect to the solar beam during imaging. For a Lambertian surface, and little or no diffuse irradiance, c_i equals cos L, where L is the angle between the solar beam and the normal to the surface of pixel i. The term X_i is proportional to the average surface reflectance in spectral band j which is assumed to be uniform over the image. The proportionality factor is a product of a quantity which is not pixel specific over suitably small areas of interest. Therefore, according to Switzer

$$X_j = (S_j T_j H_{dj}) P_j \qquad (A3.2)$$

where

S_j = System gain factor in spectral band j

T_j = Atmospheric transmission from ground to satellite in band j

H_{dj} =Direct solar irradiance in band j

P_j = The constant reflectance in band j, assumed to be Lambertian.

The additive term d_j is the unknown atmospheric path radiance for spectral band j and consists of radiation scattered into the field of view of the sensor which never reached the surface.

The above parameters were estimated by using the covariance matrix method (CMM) technique (Switzer, 1982). This method uses least squares to find a set of path-radiance values which minimize the sum of squares of the raw digital number minus estimates of the information plus path-radiance terms. According to Switzer, if we average over i pixels then the Equation becomes:

$$\bar{Y}_j = \bar{c}X_j + d_j \qquad \text{(A3.3)}$$

By subtracting Equation A3.3 from Equation A3.1, a matrix A can be obtained which has rank 1. That is,

$$[A]_{ij} = (Y_{ij} - \bar{Y}_j) = (c_i - \bar{c})\, X_j + n_{ij} \qquad \text{(A3.4)}$$

By taking the product of the transposition of the A matrix in this Equation with A, the image covariance matrix (A^TA) can be obtained. This may be decomposed into eigenvalues and eigenvectors as:

$$A^TA = V \Lambda V^T \quad \text{(Covariance matrix)} \qquad \text{(A3.5)}$$

where

$\lambda_1, \lambda_2, \lambda_3,$ ------- λ_n are eigenvalues

$\underline{V}_1, \underline{V}_2, \underline{V}_3$ -------- $\underline{V}_n$ are eigenvectors

The application of Factor Analysis (Joreskog et al., 1976) to this case follows by noting that the expected covariance matrix, based on the model, has the form

$$\alpha \, \underline{X} \, \underline{X}^T$$

$$\alpha = (c_i - \bar{c})^2$$

which can be equated to the first eigenvector and eigenvalue combination, with allowance for noise, as

$$(c_i - \bar{c})^2 \quad XX^T = (\lambda_1 - \sigma^2) \, \underline{V}_1 \, \underline{V}_1^T \tag{A3.6}$$

where an estimate for σ^2 is $= (\lambda_2 + \lambda_3 + \lambda_4)/3$ (A3.7)

Hence, $\underline{V}_1 = \underline{X} / |\underline{X}|$ (A3.8)

where

$$|\underline{X}| = (X_j^2)^{1/2} \tag{A3.9}$$

and $(\lambda_1 - \sigma^2) = |\underline{X}|^2 \; (c_i - \bar{c})^2$ (A3.10)

Therefore, the basic model for $\underline{d}$ may be expressed as:

$$\bar{Y} = \bar{a} \, \underline{V}_1 + \underline{d} \tag{A3.11}$$

or

$$\underline{d} = \bar{Y} - a \, \underline{V}_1 \tag{A3.12}$$

where

$\bar{a} = |\underline{X}| \quad (c_i - \bar{c})^2$ is undetermined (A3.13)

Switzer computes $\bar{a}$ such that $d_7 = 0$ but often it is observed that $d_j > Y_j^{min}$ where c is yet to be determined. Effective d_j values which do not give such results can be calculated by requiring that

$d_j < Y_j^{min}$ and a = minimum (A3.14) where Y_j^{min} is the minimum value in band j. The final solution can be expressed as:

$$\bar{a} = \text{maximum} \left| \frac{Y_k - Y_k^{min}}{V_{1K}} \right| \qquad \text{(A3.15)}$$

The dark values calculated for the two images used in the present study were as below:

YEAR	BAND 4	BAND 5	BAND 6	BAND 7
1980	16	8	2	0
1984	15	8	3	1

A3.4 DIGITIZING CLOUDS AND OCEAN

Both manual digitizing and spectral digitizing were used in this analysis.

Ocean areas were removed from all the images using the mDIGIT program of the microBRIAN package. This was done by specifying the area to be removed on the screen with the help of a cursor. The resultant images without the ocean area were then analyzed throughout the study. The main objective was to avoid unnecessary generation of spectral classes in the classification process and to reduce computing time.

The 1980 image had cloud cover over some parts of the study area. These were spectrally removed by using the SPDIG program. This program uses a specified set of themes defined by a set of lower and upper brightness values on each band to separate the origional image into two images, one consisting of pixels which fall within the bounds of all the themes and the other consisting of the complement of the first.

Using the mTRAIN program a number of themes were defined from the cloud covered area and all the pixels falling in the specified themes were spectrally digitized out. An attempt was also made to remove cloud shadows by defining their themes. Unfortunately, cloud shadow could not be spectrally digitized out because of the similarity between the pixels under cloud shadow and high relief shadow. Therefore, the cloud shadows were left as such in the raw data.

A3.5 IMAGE RECTIFICATION

The Landsat MSS data contain certain geometric errors that need to be corrected if the data are to be accurately registered onto a map base, registered to some geographical reference system, or entered into a geobased information system.

The geometric errors can be either systematic and predictable or variable and measurable. The systematic and predictable geometric errors include skew caused by rotation of the earth under the satellite and variable pixel size caused by the varying velocity of the mirror scanning mechanism. Variable and measurable error includes distortions caused by variations in spacecraft velocity, altitude and attitude. Because the systematic errors are predictable, algorithms have been developed to correct for these errors as a pre-processing step. When errors are introduced that are variable in nature, the effects are not predictable, thus to correct these errors, they must be measured

Jupp et al. (1982) developed a satellite model which takes into account the above mentioned distortions.

In the present study the rectification between the Landsat image and the 1:100 000 topographic map grid was achieved by using this model. The precise registration between an image and a map requires the use of selected Ground Control Points (GCP'S) in conjunction with the satellite model, to accurately convert map coordinates to image coordinates. See Figure A3.1 for the steps involved in this process in the microBRIAN system.

GCP'S are points which can be easily identified on both the map and image being used. Generally these points are located on permanent landscape features such as road intersections, coast line and watering points etc. The GCP'S are to be used to model parameters in a least squares fashion so their spatial distribution is very critical.

Because the north eastern region of Tasmania has many water features, data from one of the MSS infra-red bands (band 7) was used to pinpoint coastal points, river bends and dams etc. For other points, the remaining bands 4 and 5 were used individually to point out the exact location. Steiner and Kirby (1977) discussed the accuracy with which GCP'S can be chosen both on maps and Landsat images.

In this study 86 and 92 spatially well distributed GCP'S (see Table A3.1) were selected from the two Landsat images under consideration for which exact map coordinates (Northing and Easting, in meters) could be determined from the Australian Map

Table A3.1

Results of geometric rectification

		RMS	PRESS
	1980		
Northing error (meters)	Affine model	32.90	60.14
	Bilinear model	32.59	61.37
	Quadratic model	32.90	53.45
Easting error (meters)	Affine model	32.50	59.07
	Bilinear model	32.00	59.87
	Quadratic model	30.68	58.78
R^2		.957	
Number of GCP'S		86	
	1984		
Northing error (meters)	Affine model	30.50	51.90
	Bilinear model	30.10	53.59
	Quadratic model	28.60	53.67
Easting	Affine model	45.10	67.73
	Bilinear model	44.18	77.19
	Quadratic model	41.20	77.64
R^2		.921	
Number of GCP'S		92	

RMS --- root mean square error

PRESS--- predictive error

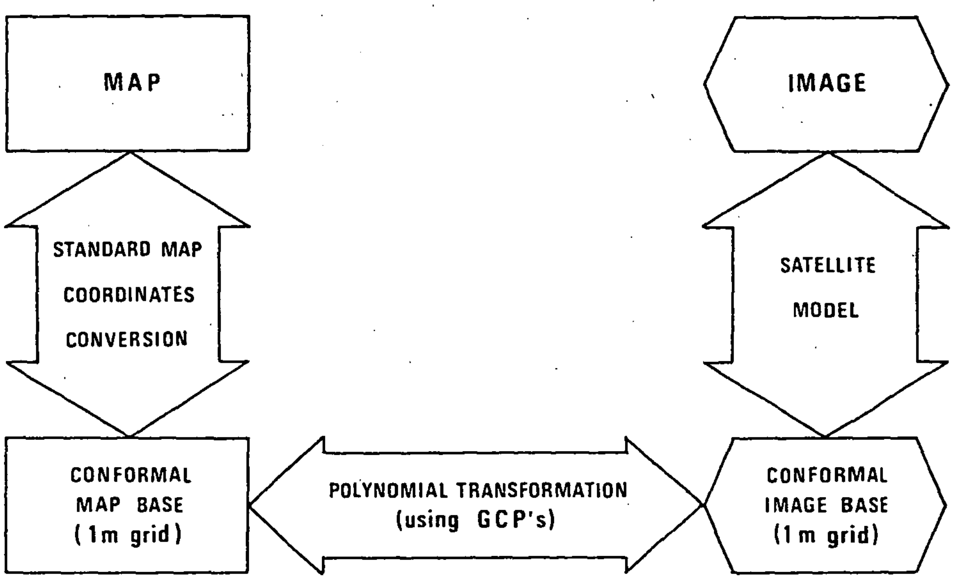

Figure A3.5 : Conversion of image coordinates from map coordinates using microBRIAN rectification programs.

Grid. These points were then converted from their initial map/image coordinate system to a conformal base grid using standard map/satellite models in the microBRIAN software.

As a next step the GCP'S were passed through the SIEVE program. This program uses a statistical test, based on the assumption of an affine relation between the map and image, to help identify data which is in error (or outliers). Outliers may be due to human error in assigning map/image coordinates or poorly selected control points.

Finally, once the outliers or bad points are sieved out, then the problem of registration becomes one of estimating the statistical regression parameters. This subject has been well documented by Guest, 1961; Bard, 1974; and Jupp et al. 1984.

Using microBRIAN, polynomial models were fitted between the two sets of conforming GCP'S coordinates and the model resulting in the least error in each direction i.e northing and easting was selected. See Table A3.1 for the models applied and their results for the two study images. The resultant parameters of the selected models were then used to produce rectified Landsat images on the Applicon inkjet plotter. The pixel size measured by the model was used to calculate the total area under each land cover class.

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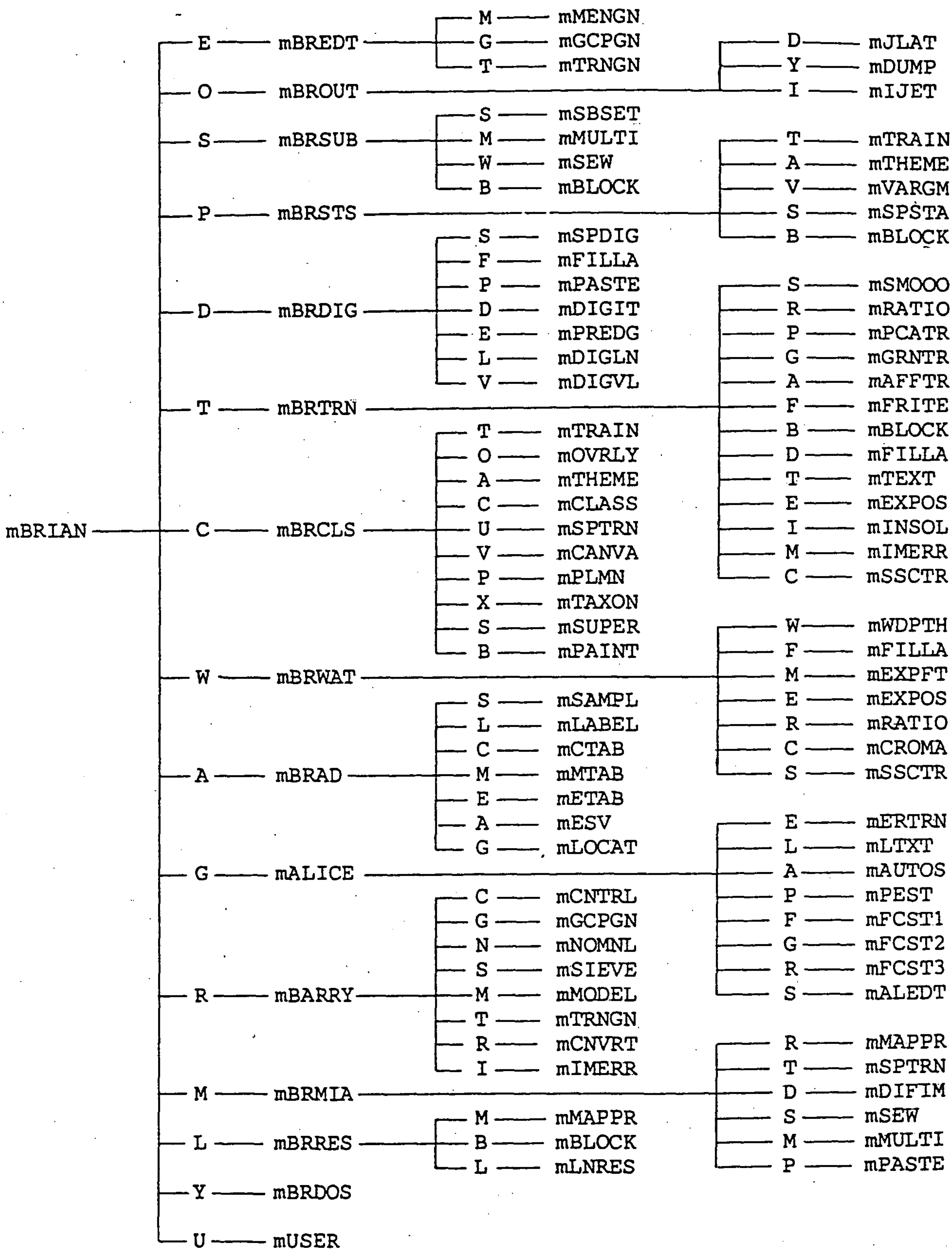

Figure A4.0 : Structure map of microBRIAN.