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**EROSION AND LAND USE IN THE POHANGINA REGION:
A STUDY USING GIS AND REMOTE SENSING**

A thesis presented in partial fulfilment of the requirement for the
Degree of Master of Applied Science in Soil Science,
Massey University, Palmerston North, New Zealand.

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ABSTRACT

In this study a combined remote sensing and GIS approach, using aerial photographs, a SPOT satellite image and a digital elevation model was employed to extract hillslope units and watershed boundary maps. The acquired data were also used to investigate relationships between topographical features (slope angles and slope aspects) and soil slip erosion and land management practices in the Pohangina region.

The procedures were first developed on a representative area. It was typical of the district in term of the climate, topography, soils, geology and land management practices. These methods were then used to identify those areas most susceptible to soil slip erosion in the Pohangina region.

A raster GIS and image processing package (IDRISI for Windows) was used to analyse the remotely sensed data/digital elevation model and to create different maps for investigation.

A simple technique for extracting watershed boundaries and mapping hillslope units was also developed.

The slope aspects facing N & NE are more susceptible to soil slip erosion than other aspects. It was also found that this erosion occurs equally on all slope classes. Four major land management practices were used in the representative area. These were pasture, exotic forest, spaced planting and reversion to bush. Nearly 95 % of erosion has occurred in pasture, 4.1 % in space planted areas, 1.3 % in exotic forest, and no erosion occurred in areas reverted to bush.

The soil slip susceptibility map of the Pohangina region was created to assist in the allocation of soil conservation practices. This study has shown nearly 90% of the areas susceptible to slip erosion (2850 hectares) are presently not covered with suitable vegetation.

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“ Dedicated to my parents”

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CHAPTER ONE

Introduction

1.1 Introduction

Erosion is a natural geological process that occurs over a long period of time to shape the land. However accelerated erosion can result from the physical disturbance of the soil and clearance of vegetation, which exposes the soil to the elements, (Manawatu-Wanganui Regional Council, 1995).

New Zealand is geologically young with a dynamic tectonic setting. Mountain and hill landscapes dominate New Zealand. Mountain lands above 1000m occupy around 20 % of the land area while at least 40 % is steep, non arable hill country below 1000m referred to as hill country, (Blaschke, 1992).

Erosion is the biggest factor in soil deterioration in hill country farms. Much of the hill country grazing land in the North Island is susceptible to slip erosion, (Clough and Hicks, 1993).

Erosion may seriously reduce the productivity of the land and adversely affect the environment; its result can be visually spectacular or it may be less obvious but no less serious. Erosion is not always regarded by the farmers as a major problem in the use of the land, and they often need to be persuaded to adopt practices to minimise erosion

The Pohangina Valley is situated approximately 25 kilometers north-east of Palmerston North, on the western edge of the Ruahine Ranges. It is centered around the Pohangina River, which runs in a south-south-west direction to meet with the Manawatu River at Ashhurst. Along the

western side of the valley is the Pohangina Anticline, on the other side of which runs the Oroua River .

Of the hill country grazing land in the North Island which is susceptible to soil slip erosion, major areas of concern are Taranaki, Wairarapa, Manawatu-Wanganui, and the East Coast hill country. The Pohangina district lies in the Manawatu-Wanganui Region. It is the unstable geology underlying the area, that renders the Pohangina hill country so prone to soil slip and gully erosion.

The Pohangina district is an eastern extension of the east Taranaki-Wanganui country, (Molloy,1988). The underlying lithology in the area between the Pohangina and Oroua Rivers is made up of Castlecliffian marine sands. These sands were laid down in a shallow beach environment, similar to Himatangi today, between 350,000 and 1.6 million years ago, (Macpherson,1985). The sands are young and unconsolidated, as they have not yet had time to lithify. As the Castlecliffian marine sands have never been deeply buried, they are still soft and loose. Water easily infiltrates the sand, due to their very porous nature. Some minor silts between the sand beds tend to be aquacludes, which do not transmit water, creating an almost impermeable layer for water to sit on. Dips in the strata are very shallow, so the beds are almost horizontal. Beds near the Pohangina River tend to tilt more strongly towards the river, (Macpherson, 1985).

Soil in the Pohangina district also contributes to the potential for severe slip erosion. The soils are mapped as Pohangina steep land soils, (Rijkse, 1977). These are shallow soils, with a weakly developed structure, and they are easily infiltrated by water.

Different soil conservation practices have been successfully carried out in this area to protect the land against the erosion. Exotic forestry has

become a popular option, and retiring the worst land to native bush is also common.

The benefits of soil conservation measures are often not immediately apparent (Weber et al, 1992). Quantitative assessment of soil slip erosion is useful to identify which topological factors are more important and it also helps us to assess the different soil conservation practices.

Remote sensing techniques provide an approach to extract variables concerning soil erosion at varying temporal and spatial scales. A Geographic Information System (GIS) can effectively store and manipulate the large amount spatial data provided by remote sensing and can effectively display spatial information that might be useful for analysing erosion and its relationship to the physiography. In this study we have used colour stereo aerial photographs and a spot image as remote sensing data and a digital elevation model as base data. Idrisi for Windows software was used to analyse and manipulate the data.

The ultimate aim of this investigation is to use GIS and remote sensing to develop a technique which can be used to determine the effect that topological features have on land management practices, and also identifying and predicting the areas which are more susceptible to erosion in the study area.

1.2 Objectives of this study:

The objectives of this study are :

- To determine if any relationships exist between soil slip erosion and slope angles and aspects in a representative study area.
- To compare the extent soil slip erosion occurring in hillslopes under different vegetation covers.
- To develop a technique for delineating hillslope/ landform units using a DEM.
- To identify and predict the areas which are more sensitive to erosion
- To promote land management practices which are more suitable for the control of soil slip erosion in the study area.
- To extend these techniques over the Pohangina region.

CHAPTER TWO

Literature Review

2.1 Erosion:

Soil erosion is a major cause of land degradation in New Zealand. New Zealand is a geologically unstable country with a climate that is usually wet but interspersed by droughts. These three factors combine to render a landscape susceptible to erosion, especially when heavy rains fall on land that is underlain by young, weak rocks or by older rocks that have been uplifted and shattered by earthquakes.

Much of New Zealand was forested before humans arrived. The forest developed in isolation with no interference from grazing or browsing animals. When Polynesian and European settlers arrived, human use of land did not alter the land's susceptibility to these natural processes but sometimes changed the rate, as settlers cleared vegetation; planted crops and grazed livestock; cultivated soil, fertilised it and applied pesticides.

The natural process of erosion only becomes perceived as a "problem" where it disrupts farming or other land uses. The problems associated with erosion are loss of soil and those nutrients contained with it (a legacy from the cleared native vegetation) and a reduced carrying capacity of the land.

Soil erosion is physical removal of soil through:

- Surface detachment of individual particles by wind, rain and frost.
- Gullyng by surface and subsurface runoff.
- Deep-seated mass movement by earthflows and slumps.
- Shallow mass movement by slips.
- Channelised mass movement by debris avalanches and debris flows.

There are three general types of soil erosion which have occurred in New Zealand (Eyles 1983) :

- 1) Surface erosion (sheet, wind and scree erosion).
- 2) Fluvial erosion (rill, gully, tunnel gully and streambank erosion).
- 3) Mass movement erosion (soil slip, earth slip, debris avalanche, earth flow, slump and mudflow erosion).

Soil erosion causes the loss of pastoral production and soil fertility, widespread damage to public and private assets, and also a reduction in water quality through sedimentation.

The nation wide extent of soil erosion has been surveyed several times; most recently by New Zealand Land Resource Inventory (Eyles 1983). This shows land's susceptibility to different erosion processes that is, the inherent risk of erosion occurring due to the natural soil characteristics, underlying geology and slope, irrespective of external influences such as climate or human use of land); also its potential for future erosion if in agricultural use. A substantial area of every region is erosion-susceptible, but areas with potential for very severe to extreme erosion are restricted to the mountains, and to pockets of unstable hill country. 11% of the nation's agricultural land are in Manawatu-Wanganui and 58% of these lands are susceptible to erosion. Erosion-susceptible land of Manawatu-Wanganui has been categorised to the following types of erosion; 25% surface erosion, 10% gullies, 20% deep mass movement, 39% shallow mass movement and < 1 % debris avalanches (Clough and Hicks, 1993). [Studies of the Manawatu River indicate that, on average, one tone of soil goes down that river every 12 seconds, day and night, year in year out. When the river is flood, this amount greatly increases.] The largest figure ever recorded in the Manawatu was 10 tones per second; this was during a 24 hour period of

a major flood in the early 1970s. Some of the load is the result of normal erosion processes which have been in action for thousands of years, but much has been added as a result of manmade changes. To prevent such erosion and sedimentation, and to target erosion control measures more efficiently, the types of land most susceptible to landslide damage must be identified. Quantifying erosion susceptibility is a key element in predicting future erosion damage. In this study past erosion events were evaluated and areas more susceptible to future erosion were identified to enable more effective land management.

2.2 Gully Erosion

“Gully erosion is the removal of soil or soft rock material by water, forming distinct narrow channels, larger and deeper than rills, which usually carry water only during and immediately after rains.” (Bates and Jackson 1980).

Gullies were distinguished from rills in that they were more than 60 cm deep and 30 cm wide (Brice 1966), disrupted normal cultivation practices and were considered to be permanent rather than ephemeral. The morphology of gullies is diverse, ranging from large amphitheater-shaped gullies, such as the ‘Tarndale slip’ (Allsop 1973), to discontinuous, elongated, ‘sawcut’ shaped gullies in Taupo Pumice Formation flow tephra (Blong 1966). Gully erosion often occurs either in association or as a complex with one or more other erosion types. For example, in jointed mudstone and fine siltstone lithologies, gully erosion commonly occurs as a complex with earth flow erosion. Gullies cut back into the distributed material of the earthflow, decreasing stability and initiating secondary earthflows within the main movement. Gully erosion is widespread in both islands. In the North Island it was the third most

extensively mapped erosion type after soil slip and sheet occurring on a wide variety of rock types and the sixth in the South Island.

In 1979 the dramatic rates of gully erosion in the unconsolidated sands country between the Pohangina and Oroua rivers prompted Brougham and O'Conner to write that a radical change in land use such as the total afforestation of all gullies would be required to cause a significant reduction in erosion and sediment transport from the gully systems.

Tree planting and retiring land from production were practices used to protect the areas that were affected by gully erosion.

2.3. Mass Movement Erosion

Soil loss by mass movement is the most significant type of erosion in the steep hilly landscapes which occupy more than 60 percent of New Zealand's land area. Five types of erosion are identified in this group; soil slip, earth slip, debris avalanche, slump and mudflow erosion. Mass movement, as the name suggests, is the downhill movement of entire blocks of soil and rock. The movement is usually quick, as in "slip".

Shallow mass movements or soil slips, are one form of erosion that is widespread in the North Island, and they are the dominant erosion processes where poorly consolidated Tertiary lithologies form the soil parent material. Landslides occur both under natural forest and grassland vegetation, and under the introduced pastoral grasslands which have largely replaced them (O'Loughlin and Owens, 1987; Blaschke et al., 1992). After deforestation, landslides occur more frequently (Hicks, 1990a; O'Loughlin and Owens, 1987; Sidle et al., 1985; Trustrum et al., 1990) and progressively removed soil form under the indigenous forest, which is replaced by shallow soil formed under a new vegetation cover, commonly pasture or scrubland (Blaschke, 1988; Trustrum and DeRose,

1988). Thus a net loss of soil has occurred since deforestation; the rate of this soil loss is an important element in the management of affected landscapes. Soil slip erosion is defined as the rapid sliding or flowing of soil and subsoil, exposing a slip surface less than one meter below the original surface. Soil slips occur when there is a prolonged period of wet weather, as in the Wairarapa in 1977, (Crozier et al, 1980) or high intensity rainfall over a short time, as happened in northern Hawkes Bay in 1985, (Harmsworth et al, 1987). During the rainfall events, the soil becomes saturated as the pore spaces fill with water and force the soil particles apart (National Water And Soil Conservation Authority, 1985). This weakens the soil, causing the top and the subsoil to move downhill. A bare slip scar, usually less than 1 meter below the original surface, is exposed. Soil slip erosion is the most extensive and economically most important erosion in the North Island where 30% of the land area are affected. In the South Island it is second only to sheet erosion, with 24 % of the area being susceptible to slipping. Slip has serious consequences, such as blocked roads, silted drains and watercourses, stock losses and reduction of potential production.

The occurrence and severity of soil slips depend mainly on the steepness of slope, the underlying rock type and the vegetation cover. Slips are most likely to occur on steep slopes and are rarely found where slopes are less than 16 degrees. They can result in an immediate and often dramatic reduction in pasture productivity on steep hill country (Lambert et al. 1984; Trustrum et al., 1984). Rocks such as mudstone, siltstone and sandstone in the North Island and mudstone, sandstone, conglomerate, granite and gneiss in the South Island, tend to be the most susceptible to slipping. A dense covering of vegetation will protect and bind the soil, reducing the chances of a slip.

Uniformity of slope angle, and steep but rounded interfluves in the Pohangina district suggest a period of greater slope stability before deforestation (Heerdegen, 1982). However, most of the indigenous forest in the Pohangina district was cleared by 1906 (Wright, 1968). The land was put mainly into sown pasture, and slipping, slumping, and gully erosion were soon noted by locals. It is the unstable geology underlying the area, that renders the Pohangina hill country so prone to soil slip erosion.

2.4 Slip Erosion and Slope Angle and Aspect

Several previous studies have shown a relationship between slope aspect and the distribution of soil slip erosion. A regional survey of mass movement in the Wairarapa hill country during the very wet winter of 1977 by Crozier et al (1980) found aspect was the most influential factor involved in the location of slips. Most soil slip occurs on upper slopes with a northerly or easterly aspect.

Following Cyclone Bola, 1988, the majority of soil slips in a study on Arai-Matawai and Emerald Hills stations, in the Te Arai catchment, were found to have occurred on slopes with a northerly, northeasterly or a easterly aspects (Veld and de Graaf, 1990). They proposed that north-facing slopes were more susceptible to erosion from a summer storm because they are steeper and, intercepting more sunlight, are much dryer than slopes with other aspects. Poorer pasture and less organic material in the soil results in less infiltration of rain water, greater surface runoff and surface erosion. A study in the Raukumara Peninsula following two storm events also found most slips occurred in the north and east facing octants and on upper slopes (Philips, 1988). However aspect had no effect on distribution of soil slips in a part of the Pohangina district following a

prolonged wet winter and spring in 1992 (Lough, 1993). This erosion followed a long wet period as did the erosion in the Wairarapa in 1977, but the lithology of the Pohangina area is different from that of the other studies quoted here. The unconsolidated Pleistocene marine sands are more likely to erode during heavy rain than the more indurated lithologies of the other study areas. This proneness of lithology to slip erosion may have been a greater factor than slope aspect.

The incident of slipping in any one area increases with slope angle (Eyles et al, 1978). This was found to be so in the steep land hillslopes in Taranaki following two high rainfall events (De Rose et al., 1993). Increasing slope angle caused differences in regolith depth with the depth of regolith being inversely related to slope angle regardless of vegetation cover. Soil slips have been found to occur in preferential regions within a slope. In many cases the slips are eroding the edge of a cap of undistributed material which mantles ridge crests and hilltops (Crozier et al., 1980). Slips most frequently occur by preferentially removing the deepest regolith from the hillslopes. They rarely occur on spurs but may occur along the side of spurs reducing the spurs width (De Rose et al., 1993). Also slips occurred mainly on the upper part of north facing slopes on Arai Matawai and Emerald hills in East Coast. (Veld and de Graaf, 1990).

Soil slips can occur at any angle. Because of the interval of most contour data (20m), small changes in slope angle are not identified. For instance, a slope with a general slope between 8-15 degrees may have within it small areas of lesser or greater slope angle.

In fact, there is general critical slope angle below which landslips will not occur under a given set of hydrological and inherent slope conditions (such as lithology). The critical slope angle on hill country of

unconsolidated sand in the Pohangina for soil slip was 15 degrees (Lough, 1993).

2.5 The History of Soil Conservation in the Study Area

The history of the area has shown that the catchments of both the Pohangina and Oroua Rivers used to be heavily forested (Brougham and O'Connor, 1979). A considerable proportion of the original native bush of the area was cleared as early as 1906 to make way for pastoral farming. In 1906 sheep farming was beginning to dominate the landscape. Apart from the large area of state forest, and some scenic reserves and parks, the predominant land use in the Pohangina region has remained pastoral farming. The erosion problems in the Pohangina region arose because of the early methods of bush clearing, pasture growing, and the subsequent farming methods used on the land. In order to protect the region, the Soil Conservation and River Control Act (1941) led to the establishment of the Manawatu Catchment Board in 1944, which in turn led to the setting up of a 70 ha experimental farm at Te Awa in 1945. This was situated on Coulter's Line about 4 km from the top of Culling's gully on the western flank of the Pohangina Anticline. The trials conducted at Te Awa included the investigation of erosion control using engineering structures, vegetation, and improved livestock and pasture management techniques (Brougham and O'Connor, 1979). The area included a main eroding gully draining over 400 hectares, with two tributary gullies each with a catchment of 100 hectares and each showing serious advanced stages of erosion. Whereas the work with concrete and other structures in the gully floors caused considerable disappointment, it really had great value in showing their limitations and turning attention rather to vegetation control, both on the

gully floors and on the catchment. The work at Te Awa, which continued until 1964, demonstrated in a striking way, the value of repopulating the hillsides with spaced trees, and improving the hill pastures grazing management. It is also produced suitable methods of grassing slips and bulldozed tracks and showed a full correlation between the lowering of run-off and soil loss and the improvement of the pasture sward and the grazing management. The work at Te Awa had a big influence on conservation work in North Island hill country.

In the early 1960's, the Catchment Board and property owners carried out their own soil conservation works, in the form of bank protection, planting, and stop banking; and a land use capability survey of the catchment was completed. This work was only intermittent until the Pohangina-Oroua catchment control scheme was set up in 1967. The aim of the scheme was to try to control and prevent erosion in Pohangina and Oroua catchments, and to help farmers to achieve maximum sustainable production. Some areas have been planted with willow and poplar poles and stakes and eucalyptus, natives, sycamores, and Tasmanian blackwoods. Different types of engineering structures have also been built in an attempt to control the different types of erosion. In recent years because of increasing demand for timber, the farmers were encouraged to plant *Pinus radiata* on unstable land. In this study we have used the capability of GIS to evaluate the effect of these practices on soil erosion control.

2.6.0 Different Types of Land Management in the Pohangina Area and Their Soil Conservation and Environmental Effects.

Hill country in the Pohangina area has mostly been under the following major types of land cover:

- Pasture
- Pasture with Space Planting
- Forest (Indigenous, Exotic)
- Scrub

Table 2.1 shows the soil slip erosion relative to vegetation cover in a representative area of Pohangina hill country after the wet winter of 1992. According to Lough (1993), the difference in mean percentage erosion between slopes in pasture and those in exotic forest is significant at the 5% level of variance, and 60% of the slopes in exotic forest showed no evidence of erosion at all over this time period.

Table 2.1 Soil slip erosion relative to vegetation cover in the Pohangina region (Lough, 1993, p26).

Vegetation	n	Mean% eroded	standard deviation
Pasture	85	6.78(a)	5.93
Space planting	42	2.01(b)	2.52
Manuka scrub	47	0.40(b)	0.83
Indigenous forest	20	0.48(b)	0.99
Exotic forest	10	1.50(b)	2.22

a, b: There is a significant difference between means which do not have letters in common.

It is important to establish whether accelerated soil erosion is an unavoidable consequence of pastoral land use, in areas at risk, or whether it can be prevented by good management practices such as fencing, oversowing and topdressing etc.

A Hawke's Bay study was conducted by Franson and Brownlie (1996). These authors compared soil slippage on two pastoral catchments in 1943. The slip density was 296 and 232 slips/square kilometer. The catchment with higher rate of slipping was planted in pines in 1971/1972, and both catchments were reassessed after Cyclone Bola in 1988. The slip density on the afforested catchment was 22 slips/square kilometer (0.1% of the land area), whereas the pastoral catchment incurred 130 slips/square kilometer (0.9 % of the land area).

In Taranaki, (Hicks 1990b) observed that only 20% of hillslopes in pasture remained totally undamaged after an extreme storm event, whereas 50% of hillslopes in pine retained their stability. When considering the damaged slopes, those in pine had 5% or less of their surface area disturbed, compared with up to 25% for the hillslopes in pasture. There was no significant difference under indigenous scrub or bush.

Eyles (1983) estimated that only 32% or 8.4 million ha of New Zealand can be maintained without the application of specific conservation measures (i.e., wide-space or block tree planting; temporary retirement; or other pastoral management aimed at minimising erosion). The total pastoral area of New Zealand is 13.9 million ha (Ministry of Forestry 1993). Eyles' calculations imply that approximately 5.5 million ha of pasture is unsustainable in its current land use.

Hicks et al. (1993) recommended tree planting to control slip, gully, earthflow, and streambank erosion. The main mechanisms for the proven

action of trees in controlling erosion include the drying out of soil by interception of rainfall and evapotranspiration, and soil reinforcement by roots. Other mechanisms, such as adding weight to the hillslopes (surcharge) may be beneficial or detrimental, but are of minor importance (Philips and Watson 1994). Enhanced infiltration of rain water, and the leverage effect of wind on trees, may have negative implications, but they can also be considered minor. Campbell (1945) showed that surface runoff as a percentage of rain under “good grazed pasture” was 42.2% as opposed to 0.3% for forest. He also demonstrated a marked increase in soil loss as a result of livestock trampling, and considered this to be “one of the most potent factors in accelerating soil and water losses”.

A dense tree cover will usually result in drier soil than under pasture, at least to the depths of tree roots. Water adds weight to the soil, weakens soil structure, and raises soil pore water pressure thus lowering soil frictional strength.

Loss of sediment was found to be considerably greater under pasture areas compared to adjacent mature pine forest and native forest (Dons 1987, Duncan 1988). Tree cover will generally provide considerably better erosion protection than pasture or crops. Forest will have a particular influence on the stability of slopes and soils (O’Loughlin 1986). This was dramatically illustrated by the effect of Cyclone Bola on the East Coast of the North Island, where:

- regenerating indigenous scrub and forest had similar levels of protection as mature exotic forest,
- mature exotic plantations had less than 10% of the landsliding of terrain covered with pasture, and

- slopes with trees less than 6 years old fared little better than slopes in pasture.

The critical period for slope stability under plantation forestry is in the years 2 to 8 when the roots of the old stumps lose their ability to hold the soil and the young trees have insufficient root development. Debris and sediment from slope failures can still effect stream flow and water quality more than 20 years later (O'Loughlin 1986, Orwin 1991)

Erosion has been shown to be reduced by about 90% where there is close afforestation of a slope with pine trees (Hicks et al, 1993). Studies by the Forest Research Institute have shown that large areas of hill country in the Manawatu would be more profitable in forestry than pastoral farming (Pottinger, 1993). The *Pinus radiata* forest productivity site index (or its height in metres after 20 years) for the unconsolidated sandstone and moderately consolidated sandstone in the Manawatu-Wanganui region is on average higher than for most other soil parent materials present in the region, ranging from 26-30 metres (Hicks et al, 1993).

Undoubtedly there are benefits from planting trees on areas of introduced pasture and cropland, such as improved protection for soils and reduced erosion, better water quality, and increased vegetation complexity. However, if these trees become part of a plantation tree crop, then many of the benefits may not last.

Plantation forests are often in catchment areas for many river and stream systems with significant natural values, and sources of water supply for domestic, irrigation and industry. Any changes in erosion rates, and water quality and availability will have significant down stream affects. Soils do have a natural erosion such as levels found under native forest, mainly determined by rainfall, topography and geology. However, changes in land use can accelerate these levels. In areas that are

degraded and have high erosion rates, planting of trees will reduce soil loss through organic matter build-up and protection from sheet wash, ice needle erosion, wind erosion and rainfall impact.)

Roseman (1994) summarised the environmental impact of monocultural exotic plantation forestry. He pointed out that even after more than 100 years of plantation forestry, the effects of introduced species on the soil have not been studied overly much. But there has been research on nutrient depletion and replacement by fertilisers, which leads directly to problems of runoff into waterways and their subsequent eutrophication (an explosive growth of weeds, which in turn leads to oxygen depletion, killing lifeforms). Nitrogen fertilisers in particular reduce the abundance and variety of soil organisms, as a living part of soil is particularly sensitive to subsequent soil acidification. Clearfelling causes huge losses of nitrogen from forest soil. Australian studies have shown that *pinus radiata* plantations lower soil nitrogen in comparison to native eucalyptus. Fertilisers are used to replace all the nutrients-others being boron, phosphorus, potassium, calcium and magnesium.

The very fact that exotic plantations are monocultural causes problems in itself. Lack of biodiversity means few species, low genetic variations within species, a limited range of habitats and little landscape diversity.

Hicks et al (1993) noted that when steep hillslopes were allowed to revert to indigenous scrub, reduction in erosion of up to 90 % has been achieved; providing the slope is fenced to exclude livestock, feral browsers are controlled, and canopy closure is achieved. They suggest that on highly erodible soils such as those in the Pohangina-Oroua catchment slopes over 32 degrees should be retired.

The Manawatu-wanganui Regional Council (1995) encourages the retirement (and reversion to bush) of land which suffers sufficient

erosion to indicate that pastoral use is unsustainable. Already by 1971, 160ha of farm land in the Pohangina and Oroua River catchments had been retired by land owners for soil conservation purposes (Groenendijk, 1971). However, land which has suffered moderate levels of erosion may be able to sustain a pastoral system of land use if appropriate soil measures are employed (Manawatu-Wanganui Regional Council, 1995). Considerable use has been made on farms of wide spaced tree planting, usually with poplar and willows in the form of unrooted 2.5-3.5 m poles (Gilchrist et al. Undated). The purpose has been to maintain grazing right to the bole, while ensuring some degree of erosion-prevention. Wide spacing, and the relatively small diameter of a poplar's crown, enable sufficient sunlight to reach pasture on all sides of the tree. Such trees have historically had little or no commercial value, and subsidies have been necessary to ensure that adequate planting takes place. As well as the cost of tree stocks and planting, hard spaced hardwoods can sometimes require expensive protection against livestock or possums, and can depress pasture production relative to unplanted and uneroded ground (Gilchrist and Foote 1991; Gilchrist et al. Undated). The assumption that transpiration rates of such species are higher than for radiata pine may not be true (Handyside 1985), and both transpiration and interception during winter is substantially less if the hardwood is deciduous. Root strength, however, is generally twice that of radiata pine (Watson et al. 1995) although there is a need to take into account differences in root biomass per hectare.

These authors state that "as a general guide, spaced-planted poplars must be no more than 12 m apart (70 trees/ ha) on unstable parts of a slope if they are to be effective in controlling erosion. Closer spacing may be needed on particularly unstable sites.

Spaced- planting can be seen as an compromise option between the excellent erosion prevention, but minimum grazing, providedly traditional pinus radiata forestry regimes, and the sometimes severe erosion that can occur on unplanted pasture. The optimum solution will depend on the situation and the relative economics of grazing and forestry, and on value that society attaches to environmental protection.

2.7.0 Digital Elevation Model:

2.7.1 Definition of Digital Elevation Model :

Any digital representation of the continuous variation of relief over space is known as a Digital Elevation Model (DEM). The term Digital Terrain Model (DTM) is also commonly used. Because 'terrain' often implies attributes of the land surface, DEM is preferred for models containing only elevation data. Although DEM's were originally developed for modelling relief, they can of course be used to model the continuous variation of any other attribute over a two-dimensional surface.

A digital elevation model represents the shape of the earth's relief in digital form. The DEM has proved to be an especially valuable part of the digital map data base in a geographic information system (GIS) used for land management and related applications. The DEM in a GIS plays the role of contour lines and shaded relief rendering on traditional paper maps, but with greatly increased analytical potential. In addition to providing an estimated elevation value at virtually any point within the model, GIS programs can be applied to the elevation value in the DEM to determine the direction (aspect) and degree of slope at any point.

2.7.2 The need for a DEM:

Digital elevation Models have many uses . Among the most important are the following:

- 1-Storage of elevation data for digital topographic maps in national databases.
- 2-Cut -and-fill problems in road design and other civil engineering projects.
- 3-Three-dimensional display for landforms for military purposes (weapon guidance system, pilot training) , and for landscape design and planning (landscape architecture).
- 4-Analysis of cross-country visibility (also for military and landscape planning purposes).
- 5-Planning roads; location of dams, etc.
- 6-Statistical analysis and comparison of different kinds of terrain
- 7-Computing slope maps, aspect maps and slope profiles that can be used to prepare shaded relief maps, assist geomorphological studies, or estimate erosion and run-off.
- 8-As a background for displaying thematic information data such as soils, land-use or vegetation.
- 9-Providing data for image simulation models of landscapes and landscapes processes.
- 10-By replacing altitude with any other continuously varying attributes, the DEM can represent surfaces of travel time, cost, and population, indices of visual beauty, level of pollution, groundwater levels, and so on.

DEMs are an integral part of numerous GIS projects. The distribution of soil, land cover, land use, agricultural practices, wildlife habitat, and

drainage patterns all vary with the pattern of the terrain. In addition, topographic characteristics, especially the degree of slope, play a key role in analyses of watershed dynamics, erosion control studies and land use suitability assessments.

Applications that can be highly dependent on DEM data quality, range from drainage feature identification (Lee et al, 1992) and geomorphological characterisation (Dike, 1989), to watershed analysis (Fisher, 1991, 1992) and radio wave propagation (Kinder et al., 1990). DEMs have been used to such an extent in geomorphological applications that Dikau (1989) considers DEMs a necessity for quantitative analysis in geomorphology. Hydrologists such as Heerdegen and Beran, (1982) used DEMs in calculating topographical attributes and determining their influence on overland hydrological flow characteristics. Also in some cases they are being used as a cost effective tool to understand environmental processes in areas of limited land resource information (Gessler et al., 1994).

Digital elevation model (DEMs) are a good data source for landform recognition; three reasons for this are as follows. Firstly, digital elevation data are becoming increasingly available and it is now possible to generate DEMs from stereoscopic images collected by satellites like the Spot-High Resolution Visible system. In view of this, the coverage and availability of digital elevation data will increase significantly over a period of time providing a valuable new resource for studies of landforms at regional, continental, and world-wide scales. Secondly, it is easier to integrate landform information represented digitally with other data than using manually / visually derived landforms (Weibel and DeLotto, 1988). Thirdly, DEMs allow automated landform recognition.

2.7.3 Different Formats of Digital Elevation Models:

DEMs in GIS are commonly stored in two data formats. They are :

- 1) A grid of elevation values
- 2) A triangulated irregular network (TIN)

A grided DEM is sometimes called an altitude matrix. It is in a raster format, where each cell in the grid contains the numerical value that represents the elevation of a corresponding section on the earth's surface. The size of a section of earth represented by each number in the DEM is the "resolution" of that DEM. A low resolution DEM has less detail, while a high resolution DEM has more detail. The level of resolution is a relative concept. There is no set standard for what is high or what is low. In standard practices, a DEM in which each grid cell represents 100 meters on the ground would be of low resolution. A high resolution DEM would have grids of perhaps 10 meters or less. Of all the topographic attributes calculated from different resolution DEM's, slope has been found to have a remarkably stable value regardless of grid size (Panuska et al., 1991). This may well have been a function of the grain size. The adequacy of DEM resolution is considered to depend upon the characteristics of the terrain under observation, with dissected topography requiring a smaller cell size than moderate relief (Panuska et al., 1991). For example with any catchment study then, the DEM grid size must relate to the size of the feature of the interest, with high resolution DEM's necessary if small drainage features are important (Garbrecht and Martz, 1994).

Altitude matrices are useful for calculating contours, slope angles and aspects, hill shading, and automatic basin delineation. The regular grid system is not without disadvantages. These disadvantages are:

- the large amount of data redundancy in areas of uniform terrain;
- the inability to adapt to areas of differing relief complexity without changing the grid size;
- the exaggerated emphasis along the axes of the grid for certain kinds of computing such as line of sight calculations.

The problem of data redundancy when sampling has been largely solved by the practice of 'progressive sampling' (Makarovic 1973) in which stereo photographs are automatically scanned at grids of increasing detail in areas of complex relief. The data redundancy persists in data storage, however, because the continuously changing altitude surface can not be coded easily in any of the compact forms for storing rasterised data that can be used with choropleth maps. As with all grid cell data structures, the altitude matrix may be too coarse to be able to represent all the critical features of terrain such as peaks, pits, passes, ridge lines, and stream courses. The misrepresentation of these features may lead to problems when attempting quantitative geomorphometric analyses. The orientation of axes allows all computations along bearings parallel to the grid lines to be reduced to a simple row or column search, while computations at other angles require trigonometric calculations to locate the correct distances and angles. Nevertheless, in spite of these disadvantages, the altitude matrix is the most easily obtainable form of DEM.

A triangulated Irregular Network (TIN) is a representation of a surface derived from irregularly spaced sample points and breakline features. The TIN data set includes topological relationships between points and their proximal triangles. Each sample point has an x, y co-ordinate and a surface or z value. These points are connected by edges to form a set of

non-overlapping triangles that can be used to represent the surface. TINs are also called irregular triangular meshes or irregular triangular surface models.

TIN is a system designed by Peucker and his co-workers (Peucker et al. 1978) for digital elevation modelling that avoids the redundancies of the altitude matrix and which at the same time would also be more efficient for many types of computation (such as slope) than systems that are based only on digitised contours. A TIN is a terrain model that uses a sheet of continuous, connected triangular facets based on a Delaunay triangulation of irregularly spaced nodes or observation points. Unlike the altitude matrices, the TIN allows extra information to be gathered in areas of complex relief without the need for huge amounts of redundant data to be gathered from areas of simple relief. Consequently, the data capture processes for a TIN can specially follow ridges, stream lines, and other important topological features that can be digitised to the accuracy required.

2.7.4 Producing DEM's:

The DEMs are produced by using different input data:

- 1) Aerial photography
- 2) Contour lines digitised from hard copy maps
- 3) Digital imagery from satellites or aircraft

The first source, traditional aerial topography, has been used the most often and over a longer period of time than the others. It requires the collection of air photos, surveyed ground control points, and, when done on a large scale, it requires expensive, specialised equipment.

The second source, digital contour lines, is also very common. Potentially, contour interpolation has the benefit of allowing a GIS user

to create a DEM using a map, a digitising tablet and a GIS with an interpolation routine. In practice, a large, data-intensive model created through contour interpolation presents many challenges in terms of software and hardware limitations and the time required .

The third source, digital imagery, has been used less frequently for the production of DEMs, but rapid advances in digital photogrammetry have made them increasingly viable options. Digital data from satellites have been used, also radar data and digital photography are other options for data input for DEM production.

2.8 Geographic Information Systems, Remote Sensing and Related Applications

GIS are computer tools for manipulating maps, digital images and tables of geocoded (geographically-located) data items, such as the results of a geomorphological survey.

GIS are designed to bring together spatial data from diverse sources into a unified data base, often employing a variety of digital data structure, and representing spatially varying phenomena as a series of data layers.

We should carefully distinguish between the data in the system and the information that results from the system. Data provide the raw material for information much as map symbols convey a map message. For both map and information systems, the raw data are not enough; additional relationships must be constructed from the context.

The most common understanding of a GIS emphasises that a GIS is a tool. However no tool is totally neutral; a GIS can be designed to be effective and efficient for a certain range of purposes.

2.8.1 Raster and Vector Models:

Geographic information systems work with two fundamentally different types of geographic models - the "vector" model and the "raster" model. Both the vector and raster models for storing geographic data have unique advantages and disadvantages.

The raster model is particularly well suited for subdividing spatially continuous variables. The raster can be presented as a rectangular matrix of numbers, similar to a two-dimensional array in FORTRAN or BASIC, and can be stored on a disk with a simple file structure, with straightforward addressing of pixels by sequence in the file. Digital scanning devices and video digitisers produce data in raster form. Many output devices are based on raster, such as video display monitors, line printers and inkjet plotters.

The raster model is used for digital images; digital image processing and analysis are well-established disciplines with a broad range of applications in remote sensing, medical imaging, computer vision and other areas.

In raster mode, points are presented as single pixels and lines by strings of connected pixels. This is often unsatisfactory, because the pixel size is too coarse to resolve closely-spaced objects. Having fixed the size of a pixel at the time of creating a raster, levels of detail that require greater resolution are lost.

Processing raster data is efficient for some tasks, such as neighbourhood query, operations such as spatial filtering that carry out calculations on a square window of adjacent pixels, and overlay operations combining two or more images. Raster processing is not as efficient for operations like finding all the adjacent pixels belonging to one compound object that are completely contained by pixels belonging to another compound object.

On the other hand, the vector model is well-suited for representing maps. Points, lines, polygons and symbols on maps are difficult to capture with fidelity in a raster without making the pixels very small, resulting in high storage costs. In vector mode, the lines surrounding polygonal areas are made by linking sequences of points, or vertices, hence the name vector. If vertices are placed very close together, and the co-ordinates are expressed in numbers with sufficient precision, curved lines can be presented accurately. The vector model fits cartographic needs well.

Data structures needed for storage of vector data are considerably more complex than their raster counterparts and algorithms for overlaying maps in vector form are more involved.

Display of vector data on video monitors and raster plotting devices requires a conversion to raster mode.

Raster and vector models can be differentiated on the basis of how they represent space, as well as by the type of spatial objects they use. Whereas the raster model employs real or volumetric enumeration, the vector model uses boundaries or surfaces to represent areas or volumes. The raster describes real or volume elements directly; the vector model stores the boundaries of objects, and uses a labelling scheme to keep track of their attributes. This labelling scheme may involve the notion of topological attributes, that are spatial attributes that define adjacency and containment relationships between spatial objects.

One of the advantages of the raster model is that spatial data of different types can be overlaid without the need for the complex geometric calculations required for overlaying different maps in the vector model. Each layer of grid cell in a raster model records separate attribute. The cells are constant in size, and are generally square, although rectangles,

hexagons and equilateral triangles have also been used. The locations of the cells are addressed by row and column number. Spatial co-ordinates are not usually explicitly stored for each cell, because the storage order does this implicitly. Information about the number of rows and columns, plus the geographic location of the origin are saved with each layer.

The raster organisation is well-suited for modelling spatial continua, particularly where an attribute shows a high degree of spatial variation, such as data on satellite images.

An empirical raster based GIS approach to the modelling of soil slip susceptibility for production forest planning purposes has been applied by Franson and Brownlie (1996). Employing geological and topographic attributes, risk classes were assigned to each layer according to their perceived importance upon the influence of landsliding.

2.8.2 IDRISI and Its Capabilities:

IDRISI is a geographic information and image processing software system developed by the Graduate School of Geography at Clark University. It is designed to provide professional-level geographic research tools on a low-cost non-profit basis. IDRISI was introduced in 1987 and has become the most widely used raster-based microcomputer GIS and image processing software.

The raster analytical functionality of IDRISI, covers the full spectrum of GIS and remote sensing needs from data query, to spatial modelling, to image enhancement and classification. Special facilities are included for environmental monitoring and natural resource management, including change and time series analysis, multi-criteria and multi-objective decision support, uncertainty analysis (including Bayesian and Fuzzy set analysis) and simulation modelling (including force modelling and

anisotropic friction analysis). Yet, despite the highly sophisticated nature of these capabilities, the system is very easy to use.

Several soil erosion and non point source pollution models have been modified and combined with GIS software to take advantage of these new capabilities and provide regional soil erosion and non point water quality assessments during the past decades (Wilson, 1996). The spatial analysis capabilities of IDRISI can be applied to many different situations in resource management. Desmet and Govers, (1994) used IDRISI 4.0 as a GIS software to compare routing algorithms for digital elevation models and their implications for predicting ephemeral gullies. Initially, the elevation data to construct the Digital Elevation Model were obtained by digitising the contour lines from topographic map of their study area. Then this information converted into a raster DEM by using the appropriate function in IDRISI.

James and Hewitt (1993) have used a combination of IDRISI and IDIRECT (FORTRAN Visual Workbench software which produces the flow direction image from the Digital Elevation Data) and ICOUNT (A program which can be used to delineate the stream network in watershed) to illustrate the use of GIS with a model, the Water Resources Evaluation of Non-point Silvicultural Sources (WRENSS) models, to assess non-point source pollution.

2.8.3 Remote Sensing:

Remote sensing refers to the acquisition of information about objects on earth by use of sensors distant from the earth. This involves radars, multispectral scanners, and radiometers mounted on platforms such as suspended booms, aircraft, or satellites.

the detail needed. Remote sensing technology is available for many applications in the earth resources field.

The aircraft-camera combination has been the most highly developed and useful technique in remote sensing. Aerial photos provide visual inventory of a portion of the earth's surface, and can be used to create detailed maps.

Aerial photogrammetry and photo-interpretation have been used effectively for decades for cartography, thematic mapping, and resource management.

Aerial photography, in spite of some limitations of cost effectiveness and range of view, is already well known and widely accepted as a tool for planning and management of earth resources.

Satellite technology allows for large area coverage at regular intervals and reduce the cost of obtaining earth resource information while continuously monitoring earth resources.

There are several satellite systems in operation today that collect imagery that is subsequently distributed to users. Each type of satellite data offers specific characteristics that make it more or less appropriate for a particular application.

In general, there are two characteristics that may help guide your choice of satellite data: spatial resolution and spectral resolution. The spatial resolution refers to the size of the area on the ground that is summarised by one data value in the imagery. Spectral resolution refers to the number and width of the spectral bands that the satellite sensors detects. In addition issues of the cost and availability of the imagery must also be considered.

The most common satellite systems are 1) Landsat 2) NOAA-AVHRR 3) SPOT.

Satellite Pour l'Observation de la Terre (SPOT), the European satellite earth observation programme was developed by France with the participation of Sweden and Belgium. The SPOT satellites carry two High Resolution Visible (HRV) sensors capturing visible and near-infrared radiance data with multispectral and panchromatic scanning capabilities. The multispectral mode captures data in three bands (green, red and infrared). The three bands are co-registered and have a ground resolution of 20m. The panchromatic mode images data in the spectral range 0.51-0.73 micrometers at a sampling interval of 10m.

SPOT's oblique viewing capacity makes it possible to produce stereopairs by combining two images of the same area acquired on different dates and at different angles, due to the parallax thus created. A Base/Height (B/H) ratio of 1 can be obtained for a viewing angle of 24 deg. to the East and to the West. For a stereopair comprising a vertical view and one acquired at 27deg., a B/H of is obtained. Stereopairs are mainly used for stereoplotting, topographic mapping, and automatic stereocorrelation, from which Digital Elevation Models (DEMs) can be directly derived without the need for maps.

Satellite imagery was used to verify the extent of landslide damage on hill-country farms in the east of North Island, New Zealand, after Cyclone Bola (Streamland 75) . Use of images provided by the French SPOT satellite to map the extent of landslides on a farm-by-farm basis was probably a world first. The destruction caused by Cyclone Bola in March 1988 was one of the New Zealand's worst ever natural disasters. Land slipped away on many farms in unstable pastoral hill country in the east of the North Island, the most severely affected area.

Aerial photography could have given the information needed. But the area to be covered of 1200 square kilometers, was so large that it would

have taken far too long to photograph, as well as being very costly. The SPOT satellite provided clear images of the whole East Coast in less than one minute. However, as there is no satellite data receiving station in New Zealand the images took 51 days to arrive. They were nevertheless available more quickly and more cheaply than if they had been obtained by aerial photography.

In this study SPOT imagery of the Pohangina region, which was taken in 1994, was used to estimate the forest and bush cover.

2.9 The use of DEM's and GIS in Extracting Topographic Structures, Automated Mapping of Land Components .

The spatial analysis capabilities of a GIS can be applied to many different situations. A number of authors have developed automatic methods to identify various singular terrain features: streams by Mark (1984), Palacios-Velez and Cuevas-Renaud (1986) and Tarbaton et al. (1991); the delineation of (sub)catchments O'Callaghan and Mark(1984), ridges by Dymond (1992) and Riazanoff et al. (1988); watershed by Jenson and Domingue (1988), Jones et al. (1990) and Band (1986); land components by Dymond, Derosé and Harmsworth (1994) and catchment boundaries and channel networks by Morris and Heerdegen (1988), Gardner et al. (1990).

The land component is an intermediate subdivision and typically is associated with ridge crests, shoulders, head slopes, back slopes, and foot slopes (Gerrard, 1990). Land components are usually mapped at scale between 1:5000 and 1:25000. Although land units are difficult to map automatically, because of difficulties in recognising surface shape, it is possible to develop algorithms to automatically map land components as they are essentially areas of homogeneous aspect and slope.

Jenson and Domingue, (1988) developed software tools to extract topographic structure and to delineate watersheds and overland flow paths from digital elevation models. The tools are special-purpose FORTRAN programs interfaced with general-purpose raster and vector spatial analysis and relational data base management packages.

The first phase of analysis is a conditioning phase that generates three data sets: the original DEM with depressions filled, a data set indicating the flow direction for each cell, and a flow accumulation data set in which each cell receives a value equal to the total number of cells that drain to it. The original DEM and these three derivative data sets can then be processed in a variety of ways to optionally delineate drainage networks, overland paths, watersheds for user-specified locations, sub-watersheds for the major tributaries of a drainage network, or pour point linkages between watersheds.

The computer-generated drainage lines and watershed polygons and the pour points linkage information can be transferred to vector-based geographic information system for further analysis. In comparisons between the watersheds derived from the digital elevation data using the toolbox algorithms and watersheds, manually delineated from topographic maps, agreement was very close. The accuracy and detail of the results that can be automatically extracted from a DEM with these algorithms is directly related to the quality and resolution of the DEM itself.

Morris and Heerdegen (1988) also developed an algorithm to generate drainage networks and catchment boundaries from gridded ground Elevation data (DTM). They used an algorithm, known as the "sink unblocking procedure" to determine drainage direction. The information present in the drainage directions is used to determine all the points

ultimately flowing to a specified point. Defining this comprises the catchment of the point. Then an algorithm was used to determine the catchment boundary by passing outside all points at the head of flow paths leading down to the specified exit point. The channel network was then obtained by referring to the area grided as a flow directions and plotting only those flow lines downstream of points with a catchment area greater than or equal to the specified threshold.

Desmet and Govers, (1996) compared six routing algorithms for digital elevation models and their implications for predicting ephemeral gullies. They have used IDRISI -version 4.0 as GIS software . The elevation data to construct the Digital Elevation Model were obtained by digitising the contour lines from the topographic map of their research area. This vector information was converted into a raster DEM with 10 meters resolution by using IDRISI. Six routing algorithms which have been used for this study were implemented into FORTRAN programs. They found the flux decomposition algorithm has some physical basis and is straightforward to implement In this case, still results need careful interpretation: the area predicted to be affected by ephemeral gully erosion should be considered to be area at risk, not areas actually occupied by gullies.

Dymond, Derosé and Harmsworth, (1994), produced an algorithm which generates a land component map from a DTM. The algorithm essentially identifies areas of land that have approximately constant aspect and slope. They followed the following steps to generate the land component map:

- 1) Classifying of an aspect image of the area to thirteen different aspect classes (twelve aspect classes of 30 degrees and an additional class of pixels with slope angle below 4 degrees).

- 2) Dissolving the small regions that are much smaller than typical land components. This is done by replacing all the regions that were below a specific size to the most commonly occurring aspect on the perimeter of the region (using four connectivity as described by Gonzalez and Wintz, 1987). The generalising program may need to be run several times before all the small regions are dissolved.
- 3) Splitting the generalised aspect regions into lower and upper slopes, where there is a significant difference in the slope angles. A given elevation threshold, which separates upper from the lower slopes, is varied between the minimum and maximum elevation in the aspect region, in order to find the best potential split. If there is a significant difference between the upper and lower slope angles at the best potential split, then the aspect region splits into two separate land components.
- 4) Repeating the process of number 3, permitting seven types of land components (main slope, upper slope, lower slope, upper lower slope, lower lower slope, upper upper slope and lower upper slope) combine with 13 aspects classes to form 91 possible land component codes.

This algorithm first creates aspects regions by generalising an aspect map. These aspect regions can be divided into land components by grouping all pixels above or below an automatically determined contour, which approximates a slope break. Either elevation contours or contours of 'distance from stream' may be used. The land components mapped in this way give a complete polygonization of a hilly landscape and are a reasonable approximation of manually mapped land components using stereo photo-interpretation.

CHAPTER III

Description of the Study Area

3.1 Features of the Study Area

The Pohangina region is in the northern part of the Manawatu District, North Island. This area is the southern part of the Pohangina Anticline, it lies between the Pohangina River to the east, and Oroua River to the west and extends from Colyton in the south to Kimbolton in the north (Figure 3.1).

It includes the hill country, terraces, and river flats of the Pohangina and Oroua Rivers which drain the western slopes of the Ruahine Range.

Over 80 % of the area is hill and steep land where erosion, steepness, and inaccessibility may be severe to very severe limitation to agriculture production.

A representative area of the region was chosen to achieve the objectives of this study.

It is (Figure 3.2) typical of the district in terms of the climate, topography, soils, geology and soil conservation practices. The representative area is located near Pohangina, approximately 7 kilometers north of Ashhurst, between the Pohangina and Oroua rivers. It covers an area along Zig Zag Road, from Valley Road to the Finnis Road intersection and is approximately 436 hectares of steep hill country sheep and cattle farms.

The techniques developed for this study area were used to map the areas most susceptible to soil slip erosion in the more extensive Pohangina region (~23940 ha). See areas delineated by yellow line in Figure 3.2.

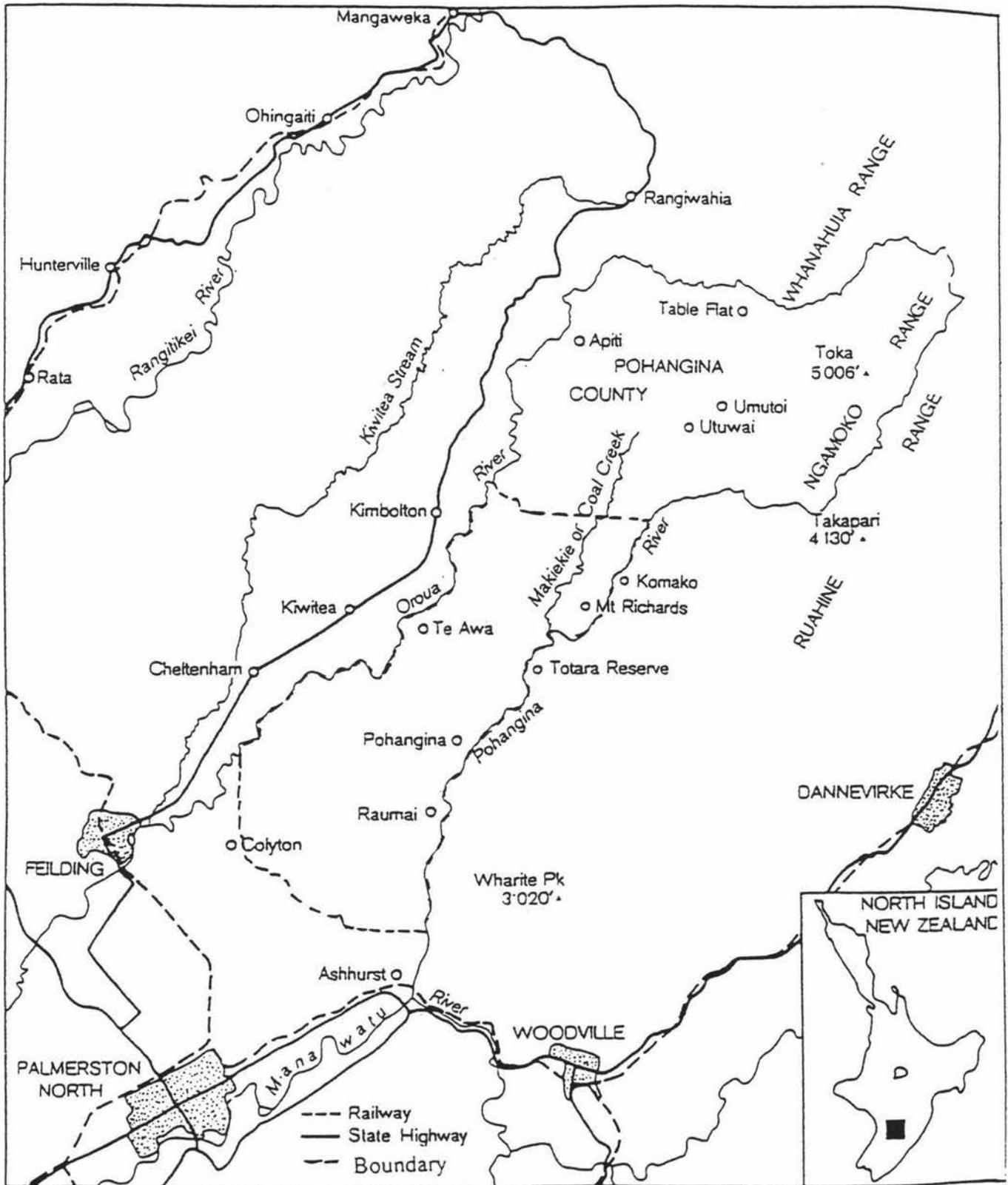
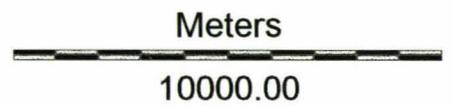
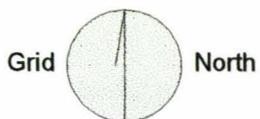
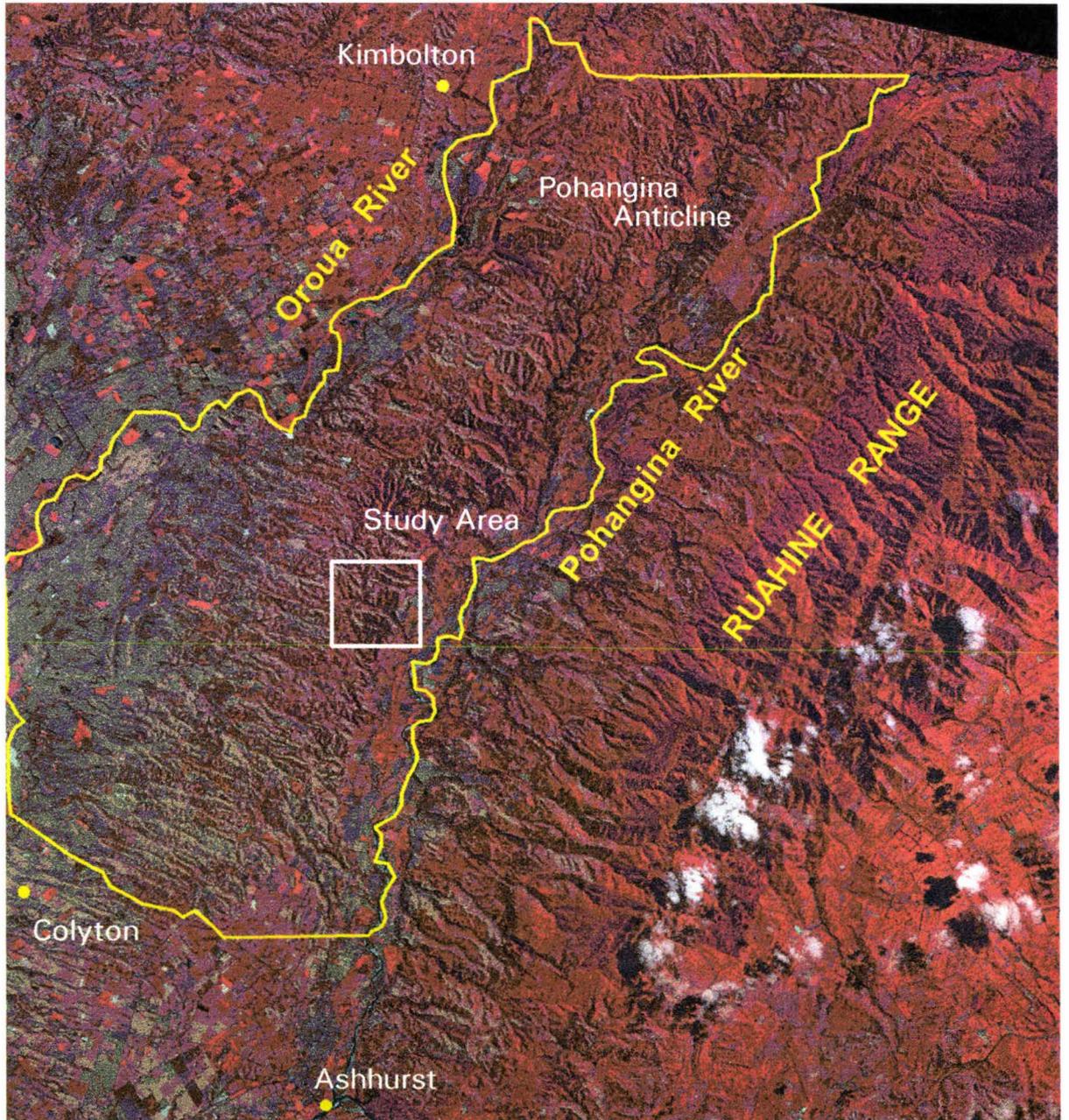


Figure 3.1 Location Of The Pohangina Anticline In Area
(Adapted From W.C. RIJKSE, 1977)

SPOT XS Colour Composite Image of the Pohangina Region



3.2 Physiography

3.2.1 Geology of the Area

The underlying lithology in the area between the Pohangina and Oroua rivers is made up of Castlecliffian marine sands.

The land in the area is rising on the Pohangina Anticline. Hence, the streams are cutting down rapidly through the soft marine sediments, leading to slope instability.

The Castlecliffian stage was originally proposed by Thomson (1916) for a succession of beds exposed on the coast between Wanganui and Patea. This stage of the Wanganui series was originally placed in the upper Pliocene (Finlay and Marwick 1940) but later workers placed the stage in the pleistocene on paleobotanical and fossil evidence (Cowie 1964a, b., Campbell 1969). This term (Castlecliffian) is now used for rocks of similar age throughout New Zealand.

Lower and Middle Pleistocene sediments (Nukumaruan and Castlecliffian stages) occur mainly west of the Pohangina River and south of the Totara Reserve. These sands were laid down in a shallow beach environment, similar to Himatangi today, between 350,000 and 1.6 million years ago (MacPherson, 1985).

During Haweran time (400,000 BP to present), local folding and general uplift occurred, forming gentle anticlines (e.g., the Pohangina Anticline). The Pohangina anticline, has a north-northeast trend roughly parallel to the Ruahine Range. Near Ashhurst the axis swings southwesterly before dying out at Palmerston North. This anticline is asymmetrical having a broad western limb with the Haweran surface and underlying beds inclined at 2-3 degrees. The narrow eastern limb shows a very maturely dissected depositional surface with dip angles of 45-60 degrees. Haweran

sediments underlie the surface with Castlecliffian and Upper Nukumaruan beds appearing at the anticline surface (Rich 1959). The dissection of the Pohangina anticline points to periods of intermittent uplift. It can be seen that two phases of local uplift accompanied folding that occurred in the past.

The sediments in the study area and over the much of the Pohangina region are geologically very young and consist mainly of loose unconsolidated Castlecliffian and Haweran sands and silts.

They were derived from several sources including the rising greywacke ranges to the east and north, the Tertiary sediments of the central North Island, and a granitic and metamorphic terrain in the northern South Island (Te Punga 1954, cited in Rolston 1973). Material was also derived from sediment deposited in the Wanganui Basin itself.

They comprise siltstones and sandstones with thin limestone bands. The siltstones are generally stable, but the sandstones show moderate slump erosion. The younger rocks of middle pleistocene (Castlecliffian) consist of loose banded marine sands and sandstones with cemented greywacke gravel bands and pumiceous bands. The sands have little strength and the resulting gullying and slope instability have created serious problems. The greywacke gravel bands outcrop in ridges and spurs and are more stable than other members of the formation.

The sands are young and unconsolidated. This means that they have not yet had time to lithify. As the Castlecliffian marine sands have never been deeply buried, they are still soft and loose. Therefore, water easily infiltrates the sands, due to their very porous nature. Some minor silts between the sand beds tend to be aquacludes, which do not transmit water, creating an almost impermeable layer for water to sit on. Dips in the strata are very shallow, so the beds are almost horizontal. Beds

nearer the Pohangina river tend to tilt more strongly towards the river (MacPherson, 1985).

Castlecliffian rocks in the Oroua and Pohangina Valleys are predominantly sands interbedded with laminated siltstones. Occasional conglomerate bands and pumice bands also occur in marine sequences or in much dissected high terraces.

3.2.2 Soil Types

Information about soils within the study areas can be obtained from New Zealand Soil Bureau, Rijkse (1977). These surveys mapped soils at reconnaissance scales, from 1:250000 to 1: 50000.

Soil in the study area contributes to the potential for severe slip erosion. The soils are mapped as Pohangina steepland soils and Ruamai hill soils (Rijkse, 1977). These are shallow, with a weakly developed structure, and are easily infiltrated by water.

Pohangina steepland soils (PhS) are the steepland soils related to Ruamai soils and they occur in most parts of the study area. Their parent materials are similar to Ruamai hill soil and slip erosion is severe. The slips heal slowly and show a tendency to erode further into small gullies.. Subsoils are very weakly structured to massive. The variability is further accentuated by differences of soil profiles between sunny drier sites and shady sites. The drier sites usually are more mottled and generally show more yellow-grey earth features.

Pohangina steepland soils are moderately leached and moderately acid. Pohangina soils are potentially not potassium deficient. Soil fertility is especially low on spurs and ridges where black beech grew before the land was cleared for pasture.

Land use on Pohangina steepland soils consists largely store and breeding sheep. Small areas have been successfully planted with *Pinus radiata*.

Raumai hill soil (RaH) has been mapped in some parts of the study area. They are derived from loose sandstones, greywacke gravel bands and pumiceous bands. Soil structures are weakly developed in topsoils and upper subsoils and lower subsoils are structureless. The loose sandy parent materials are unstable and erode easily except where cemented greywacke gravels outcrops on ridges and spurs to form a stabilising component of these soils. In unstable places where slips have occurred soil profiles consist of 5cm olive-brown friable sandy loam with some slight mottling, overlying 13cm olive-brown firm loamy sand with many mottles. This overlies pale brownish grey hard sand with abundant mottling.

The soil is moderately well drained except on lower parts of slopes where clay movement from higher part gives heavier subsoil textures. Such areas are infested with rushes and water-tolerant plants.

Raumai hill soils are weakly leached and they are near neutral in the upper horizons and slightly acid in the subsoils. Generally, these soils are low in phosphorus and, as they have low phosphate retention values, good responses would be expected from phosphate topdressing..

The hill soils are used for sheep breeding and fattening stock. Poplar and *pinus radiata* planting have been carried out successfully in places of extensive erosion.

3.3 Climate

The climate of the area is characterised by warm summers and cool winters. It has an evenly distributed rainfall and most of the rain is brought in by westerly winds.

Data supplied by the New Zealand Meteorological Service show that the rainfall pattern is largely controlled by the north-south position of the high country, which causes precipitation of moisture carried by the westerly crosswinds.

The nearest rainfall recorder stations are Te Awa, Komako, Colyton, Apiti and Table Flat. The closest wind observation is Ohakea Airfield. The average annual rainfall ranges from 1100 to 1830 mm and occurs predominantly with the prevailing westerly and north-westerly winds. It is further influenced by the orographic effects of the Ruahine Range. The seasonal variation is relatively slight with June the wettest and March the driest. Wind observations at Ohakea Airfield suggest that north-west to north winds are predominant and gales are frequent.

Wind directions available from Ohakea Airfield, the nearest climate stations taking wind records, are NW 37%; W 18%; NE 11%; SE 8%; E 7%; SE 4%; S 3%; and calm 4% (from 1939 till 1976).

3.4 Land Use And Vegetation Cover

The main land use in the study area is sheep and cattle grazing on dominantly browntop (*Agrostis tenuis*) and ryegrass (*Collium* sp) pasture.

Identification of land use patterns from air photo-interpretation was simple because they were dominated by pasture with only scattered groups of trees. The group of trees having a coarse texture with darker

tones could be identified as *Pinus radiata*, whereas those with brighter tones were generally native trees, shrubs or conservation trees.

Before European settlement commenced, about 1880, most of the area was in a native forest. These forests have been cleared from large areas and those remaining have been grossly modified.

Small forest blocks of *Pinus radiata* are scattered through out the study area. Most have been planted to stabilise slip or slump erosion. Remnant native trees such as Red Beech (*Nothofagus fusca*), Totara (*Podocarpus totara*) and regenerating native scrub-mainly Manuka (*Leptospernum scoparium*), provide a conservation function. Rushes (*Juncuss* spp) are widespread on pasture areas that have a drainage problem.

CHAPTER IV

Methodology

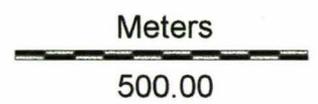
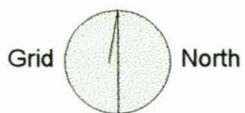
4.1 Data Collection

4.1.1 Data Sources and Their characteristics

The data sources that have been used in this study are:

- A number of colour stereo aerial photographs of area which were taken on March 1993 at scale of 1:10,000. These were scanned at 2 meter resolution. They had an endlap of 60 and sidelap of 30 percent. These colour stereo photographs have a format of 23cm by 23cm.
- A 1:50,000 topographic map-NZMS 260 T23.
- A Digital Elevation Model of the study area with 20 meter resolution.
- A SPOT (System Pour l'Observation de la Terre) satellite composite image of the entire study area, acquired on 1994. The multispectral sensors on the spot satellite consist of a high-resolution-visible (HRV) image system designed to operate with a 20 meter resolution over the wavelength range 0.51 to 0.73 μm .

An Aerial Photograph of the Representative Area



4.1.2 Software Used in This Study

The GIS software-IDRISI for Windows version 2.0, which employs both vector and raster formats was used. The system was used for both GIS data analysis and some digital image processing.

4.2 Data Input and Manipulation

4.2.1 Data Input

Clearly, aerial photographs are not in a format that can immediately be used in digital analysis. However, it is possible to scan photographs with an inexpensive desktop scanner and to create multi-spectral datasets by scanning a colour image and separating the red, green and blue bands. Several GIS/IP software systems have this capability.

An aerial photograph of the study area was scanned. The TIFF format was chosen as an intermediate file that could be further converted to the format compatible with the program used in the analysis procedures. R.G.B bands were created by extracting the Red, Green and Blue bands from colour scanned aerial photograph of the study area and imported to Idrisi.

The DEM with 20 meter resolution was originally provided as an ascii file and it was imported as an Idrisi image file for further manipulation.

A multispectral spot satellite image of the area acquired on 14th of February 1995.

4.2.2 Data Manipulation

4.2.2.1 Image Registration and Rectification

Prior to the data analyses, the processes of registration and rectification needed to be undertaken. Rectification is applied when the spatial arrangement of features in the data set is to be made conformable with a

specific georeferencing system. While in the registration process, ground features do not necessarily have to be on an absolute georeferencing scheme. Rather, they simply need to have geometric conformance from one to another. Thus the difference is that in image rectification the reference is a map in standard map projection, whereas in image registration the reference is another image (Jenson, 1986).

To transform a digital image into a corrected image corresponding either to particular cartographic projections or to the other images, the procedure essentially entails three different steps:

Identification and selection of ground control points (GCPs), choosing a mapping function, and image resampling. The last two are straightforward, while the first step relies on manual operation which can be time consuming (Chen and Lee, 1992).

A GCP is defined as a point on the surface of the earth where both image co-ordinates (measured in rows and columns) and map co-ordinates (measured in degrees of latitude and longitude, or metres) can be identified (Benny, 1983; Jenson, 1986). These points are usually well defined and spatially small such as road intersections, airport runway intersections, bends in rivers, stream junctions, jetties, prominent coastline features, etc.(Davidson, 1986; Richards, 1986). The main aim of selecting GCPs in both target and reference data is to determine the coefficient of a mapping function which relates the image co-ordinates to a reference system and brings them into conformance with one another.

Once the control points have been selected on the reference, it is necessary to locate them in the corresponding positions on the image, and to record the image co-ordinates. To identify the approximate location of a particular control point on the image, the pixels around this point were magnified and displayed on the screen. The cross cursor was

then used to indicate the GCPs position. As the New Zealand Metric Series (NZMS) co-ordinates increase to the north and east, then the image co-ordinates were recorded with ascending order from the lower left-hand corner, in lieu of using the number of columns and rows which start from top left-hand corner of the image. The latter can also be applied, but the output needs to be flipped or transposed to give the correct positions. Having noted these corresponding co-ordinates, the IDRISI RESAMPLE module was then executed. Resampling is a procedure for spatially georeferencing an image to its known position on the ground. Often this procedure is used to register an image to a universally recognised co-ordinate reference system such as Lat/Long or Universal Transverse Mercator (UTM). The resampling procedure may be summarised as follows:

- The user identifies the X, Y co-ordinates of two pairs of points that represent the same place within both the old and new co-ordinate systems . The co-ordinates of the new system may be taken from a map, from another already georeferenced image, or from a vector file.
- The user creates a correspondence file that contains these co-ordinate pairs.

Pnts

X old Yold Xnew Ynew

X old Yold Xnew Ynew

.....

- Idrisi for Windows solves an equation that describes the relationship between the two co-ordinate systems.

- Using this equation, Idrisi for Windows converts the file to new reference systems through what is termed a *rubber sheet* transformation.

This gave an indication of the accuracy of the transformation, and the first guess of the improvement needed to minimise the error. This could be identified from the total (X and Y) of root mean square (RMS) error and the residuals for each control point. Some time was spent repeating the operation until an acceptable total RMS error was obtained.

The scanned aerial photograph and RGB bands were registered using a correspondence file including eight GCPs with a very low and acceptable RMS.

4.2.2.2 Vector files

Some features such as roads, streams, buildings and different types of soil conservation practices were digitised as vector files. Some of these vector files were converted to a raster format for further manipulation and analysis. Digitising was done on screen using as a background a registered aerial photograph of the area at a scale of 1: 10,000 with a 2 meter resolution.

4.2.2.3 Binary Mask

A binary mask, sometimes called a “boolean image”, is an image which is used to mask out particular areas on a complex image. This image has only two values, usually one and zero; the 1’s represent the areas that meet the stated criteria, while 0’s represent areas that do not meet the criteria (McKendry et al., 1992). Thus, by applying a masking operation, particular features can be isolated from a scene.

Raster format files of the roads, buildings and other features which might easily be confused with slip scars were used to generate mask images of

those areas. These masks were used to exclude those features when classifying, mapping and calculating the exotic forest, spaced tree planting, natural vegetation cover and eroded areas.

4.2.2.4 Image Resizing

One of the preliminary processes is ensuring, the images are the same size and resolution. The Idrisi Window and Expand modules were used to ensure the DEM and scanned aerial image of the area had the same co-ordinate systems.

4.2.2.5 Air Photo Interpretation

Aerial photo-interpretation was carried out to identify major features on the air photographs. Stereo pairs of photographs were viewed through a stereoscope to obtain a three dimensional image. The various stages of photo-interpretation included: recognition and identification, analysis, classification and deduction (Carroll et al, 1977). These can not be easily separated as they are usually used in combination.

Recognition and identification are the direct observation of features clearly visible on air photographs. The aim of this stage was to get as complete a picture of ground conditions as possible to assist the further work in image processing. Obvious objects such as buildings, streams, forest, bushes, soil slips, ridges, valley bottoms, hill slopes boundaries, were identified in advance.

4.2.3 Data Analysis

4.2.3.1 Image Classification

The classification of remotely sensed data is aimed mainly at automatically categorising the spectral values of pixels in a given image into land use/land cover classes specified by the user. The data undergo

transformation from spectral classes into information classes. The former refers to the classes that are inherent in the remote sensor data, while the latter are those that user defines (Jenson, 1986; Jenson et al., 1983; Campbell, 1983).

In the classification procedures, feature identification can be done by means of spectral, spatial, and temporal pattern recognition. In simple terms, spectral pattern recognition refers to utilising brightness values of pixels which correspond to the cover classes being identified. Thus the procedure utilises pixel by pixel spectral information as the basis for automated land cover classification (Lillesand and Kiefer, 1987).

In spatial pattern recognition, various characteristics, such as size, texture, shape, repetition, directionality, and context, are used as the basis of feature identification.

There are two broad types of classification procedure which are usually recognised, i.e., supervised and unsupervised classification. In the supervised approach, the assumption is that each spectral class can be described by a probability distribution in multispectral space (Richards, 1986). Such a distribution will determine the probability of a pixel representing a particular class at any given location in multispectral space. It is thus important, prior to classification stage, to define representative samples for each category. This is undertaken by collecting numerical data from training areas on spectral response patterns of land cover categories. This step known as the training stage, while the next two stages of this procedure are classification and presenting output (Estes et al., 1983; Lillesand and Kiefer, 1987).

Unlike supervised classification, the unsupervised technique does not require the image analyst to collect data for training areas. The image data pixels are grouped by aggregating them into the natural spectral

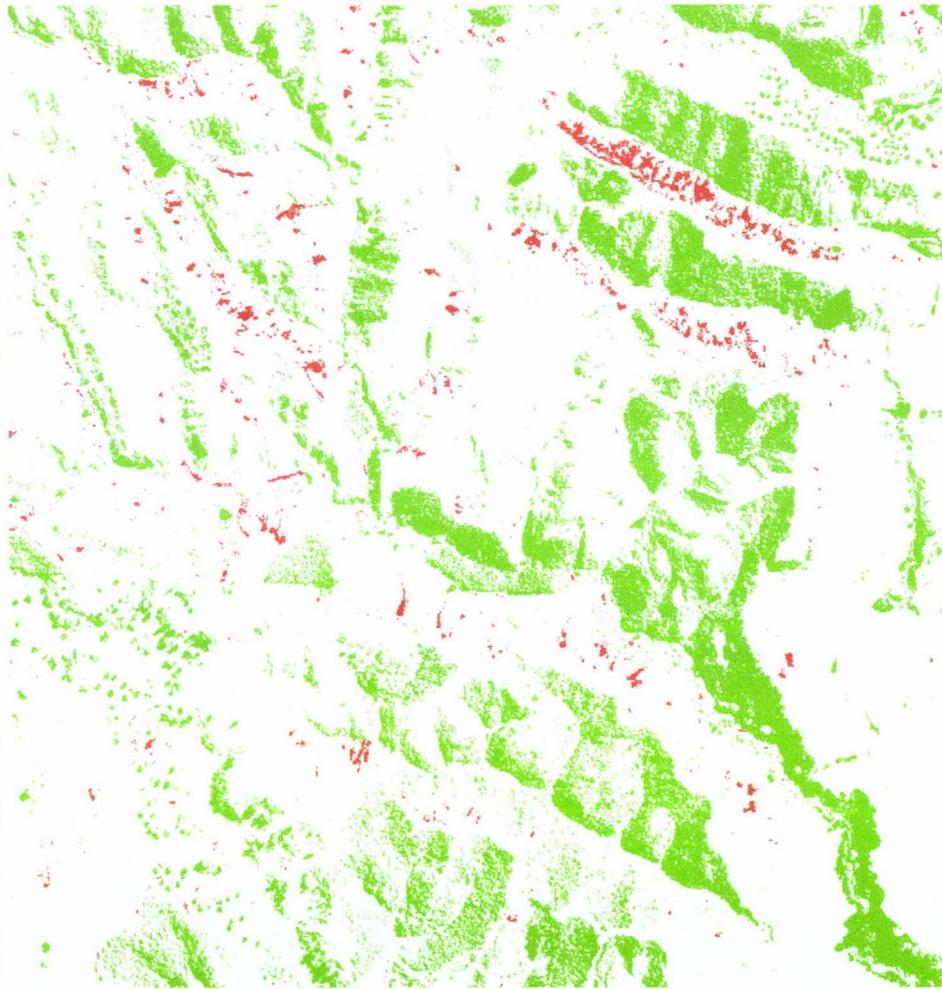
groupings or clusters present in the scene. Therefore, the procedure is accomplished on the basis of clustering algorithm (Jensen, 1986; Lillesand and Kiefer, 1987; Richards, 1986).

In this study an unsupervised classification technique was used for image classification. After considering the objective of the study, three classes of relatively static land use/land cover were selected. They were : 1) pastoral farming and 2) trees(exotic forest and space planted areas) and bushes and eroded areas.

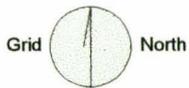
Cluster works directly with the three-bands (R, G, B) of a colour composite image of the study area. After clustering, the result was an image with 3 classes, and the next step was then to identify which class belonged to which vegetation cover or feature.

Three areas were identified as follow; 1) Pasture (356 ha) 2) Trees and Bush (74.3 ha) 3) Eroded area (5.5 ha). (Figure 4.2)

Map of the Vegetation Cover and Eroded Area



- Pasture
- Trees and bushes
- Eroded Areas



Meters
500.00

4.4 Automated Mapping of the Hillslope Aspect Units and Deriving the Sub-watershed Boundaries

4.4.1 Slope Angle

The more common representation for surfaces adopts a spaced-controlled method, usually a lattice of regular point samples, a DEM. Given the distance between sampling points, the slope can be estimated from the neighbouring values in the matrix. Slope can similarly be considered as a point attribute, but it can be also be applied to the facets between the points. Some algorithms produce point estimates of slope, while others make facet-based estimates. Three neighborhoods can be used to calculate slopes in matrix. The point based estimate can be derived from four direct neighbours along the rows and columns or from eight neighbours in all nearby cells including diagonal neighbours. An area estimate sees the cell as being bounded with four points at the corners of the cell. With the area estimate, the cell assigned the slope is not the same as the cells of the original matrix. Thus, it is more common to treat DEM slope calculations as a point matter, assigning the slope to the same points.

In raster-based models, the slope angle is usually determined by comparing the elevation of a cell with the elevation of its neighbors. In these models, the number of neighboring cells considered for comparison with a cell as well as the algorithm for calculating slope angles. Some models include all of the eight neighboring cells whereas others include all of the cells except the diagonal cells. Some, such as the slope option in the IDRISI for Windows module SURFACE, calculate slope angles ranging from 0 to 90 degrees. Slope angle image of the study area was generated and it was classified to five classes.

4.4.2 Slope Aspect and Hillslope Units

Digital Elevation Models (DEMs) can be used to derive a wealth of information about the morphology of a land surface (U.S. Geological Survey, 1987). The algorithms traditionally included in most raster processing systems used neighbourhood operations to calculate slope, aspect, etc.

DEMs are simply lists of surface elevations stored efficiently in a computer, their usefulness in the area of landform recognition has become increasingly apparent.

The more common representation for surfaces adopts a spaced-controlled method, usually a lattice of regular point samples, a DEM. Given the distance between sampling points, the slope and aspect maps can be estimated from the neighboring values in the matrix.

In raster-based models, the slope angles and slope aspects are usually determined by comparing the value of a cell with the value of its neighbors.

The surface module in Idrisi for Windows, calculates slope aspects from 0 to 360 degrees.

Slope aspects image of the study area was generated and it was classified to eight aspects.

Hillslope Aspects areas of relatively uniform slope and aspect often correspond with ridges and streams. Aspect regions, which generally span from stream to ridge, are identified by first generalising the aspect map derived from digital elevation data.

The aspect classification performs a good first cut of the landscape, regionalising many major land units that stretch from ridge to stream. This classification, however, also produces many regions that are much smaller than typical hillslope aspects units and which need to be

dissolved. These regions or individual pixels constitute noise in the map. DEMs almost always contain depressions as well which may sometimes appear as noises in the generated slope aspect image. Having an aspect image with uniform noiseless hillslope aspects units is necessary for further analysis. Therefore, the first step is to create an adjusted “noiseless” aspect map.

In this study noise was removed by filtering the classified aspect image. The gently rolling country areas (less than 7 degrees slope angle) which were classified as slope class one, were then removed from the aspect map to generate a more appropriate hillslope aspect units image. The areas which are in slope class one are not affected by soil slip erosion because this type of erosion is generally confined to areas with a greater slope.

To check the accuracy of the process and also whether the hillslope aspects units are located within their watersheds or not a technique to delineate the watershed boundaries was developed. By overlaying these boundaries on top of the hillslope aspect units map we can determine the accuracy of the hillslope aspect units.

The ability to delineate watershed boundaries without spending lot of time on topographical maps or stereo pairs of aerial photographs have always been considered by researchers.

The topographical map has always been one of the major sources of information for the derivation of catchment characteristics such as, catchment shape, aspect, slope, travel time, and so on. It requires the use the two primary information sources contained on topographical maps: contour and drainage lines. To delineate the sub-watersheds boundaries stream networks were digitised on screen using the scanned aerial photograph of the study area as a backdrop.

At this point in the processing, two data files exist; the Digital Elevation Model , and a vector file of stream networks.

The vector stream networks file was then converted to raster format and this enabled all the points ultimately flowing to a specified stream to be determined by using Idrisi WATERSHED module. By definition this comprises the catchment of the stream.

The boundaries were not very smooth. The raster sub-watershed boundaries file was converted to vector format then Idrisi LINGEN Module was used to smoothing the boundaries. The resulting boundaries were located perfectly on top of the ridges and divided the study area to its sub-watersheds.

The boundaries image was overlain on top of the hillslope aspects units image to check its accuracy. Also it could be used to target areas contributing most sediment to river and partition the watershed into a set of fundamental run off producing subregions.

4.5 Determining the Effect of the Slope Angles and Aspects on Eroded Areas and Assessing the Effect of Land Management on the Soil Slip Erosion Control in the Study Area

To investigate whether the eroded areas on hillslope aspect units were a function of slope angle or not, the slope and hillslope aspect images were combined using a crosstabulation function. Then, distribution of hillslopes within their aspects in slope classes was calculated. The next step was to determine the effect of slope angle and slope aspect on eroded areas. The distributions of eroded areas per slope class and slope aspect were calculated using the crosstabulation function.

The percentage of eroded areas in the slope classes and slope aspects, and also the percentages of slope classes in the study area were calculated.

An image of the hillslope units that were affected by soil slip erosion was generated using the Group module in Idrisi to identify each hillslope as an individual unit and then crosstab with image of eroded areas. The resulting image was classified to highlight those hillslope units that were affected by soil slip erosion.

A vegetation cover map of the study area was delineated from the aerial photograph by using a combination of on screen digitising and an unsupervised classification technique..

After comparing this map and the eroded areas map, the distribution of eroded areas in each vegetation type was calculated and then compared.

The percentage of natural vegetation cover on different aspects was also and calculated.

4.6 Mapping of the Areas Most Susceptible to Soil Slip Erosion in the Pohangina Region

The same technique as described before was used to generate slope classes and hillslope units images of the larger Pohangina region.

To generate the image of the areas susceptible to soil slip erosion, at first areas with susceptible rock types such as Unconsolidated sands, Loess and any combination of these with other rock types were extracted from LUC data base information using DATABASE QUERY Module of Idrisi and then their distributions according to hillslopes and slope classes in the Pohangina region were calculated.

The second step was classifying the areas that were facing towards N & NE and also on rock types susceptible to soil slip erosion. This was

done by classifying the hillslope units image and overlaying the resulting image with the image of the rock types susceptible to soil slip erosion.

A third step was removing the areas with deeply rooted vegetation cover from the resulting image. The deeply rooted vegetation cover image of the study area was generated from SPOT satellite composite image of the area. It was classified using an unsupervised classification to generate image of the forest and bush. Also distributions and percentages of the deeply rooted vegetation cover in erosion-susceptible areas were calculated. The areas with deeply rooted vegetation cover which were located in erosion-susceptible areas were eliminated by using a mask leaving an image which highlighted areas with:

- Unconsolidated sands included in the rock types,
- N and NE facing slopes > 7 Degrees,
- Pasture as the vegetation.

CHAPTER V

Results and Discussion

5.1 Automated Mapping Of the Hillslope Aspects Units , Using a DEM

5.1.1 Slope Angle

A slope angle map was generated from the DEM using the SURFACE Module in Idrisi. The maximum slope angle was 29 degrees, and the slope angle classes were delineated as follows:

- Class one 0 to 6 degrees
- Class two 7 to 11 degrees
- Class three 12 to 15 degrees
- Class four 16 to 20 degrees
- Class five > 21 degrees

The distribution of slope classes within the study area and the classified slope angle maps are shown in Figures 5.1 and 5.2 respectively. Slopes less than 11 degrees account for 67% of the study area and slopes between 12 and 20 degrees occupy only 30 % of the area.

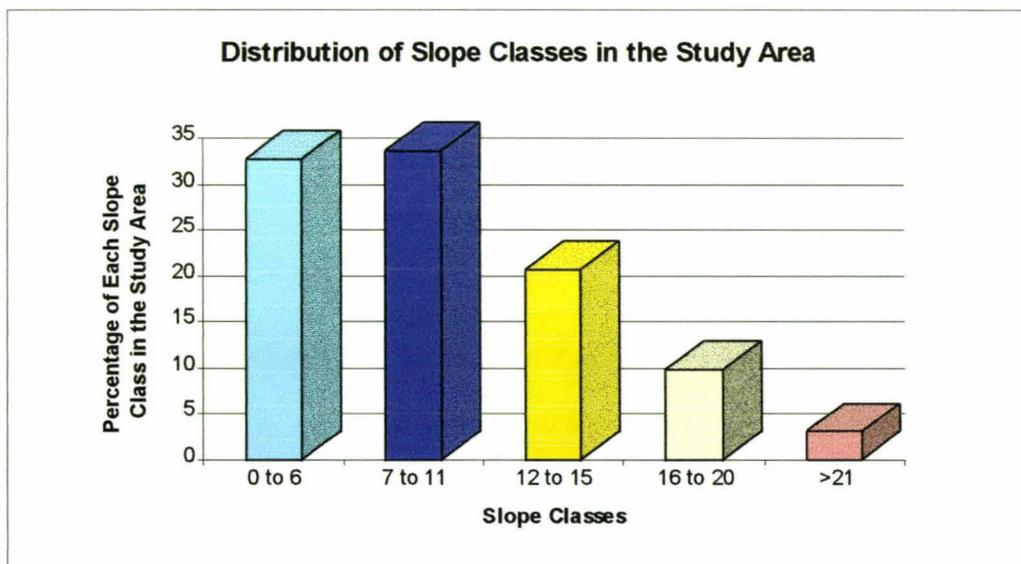
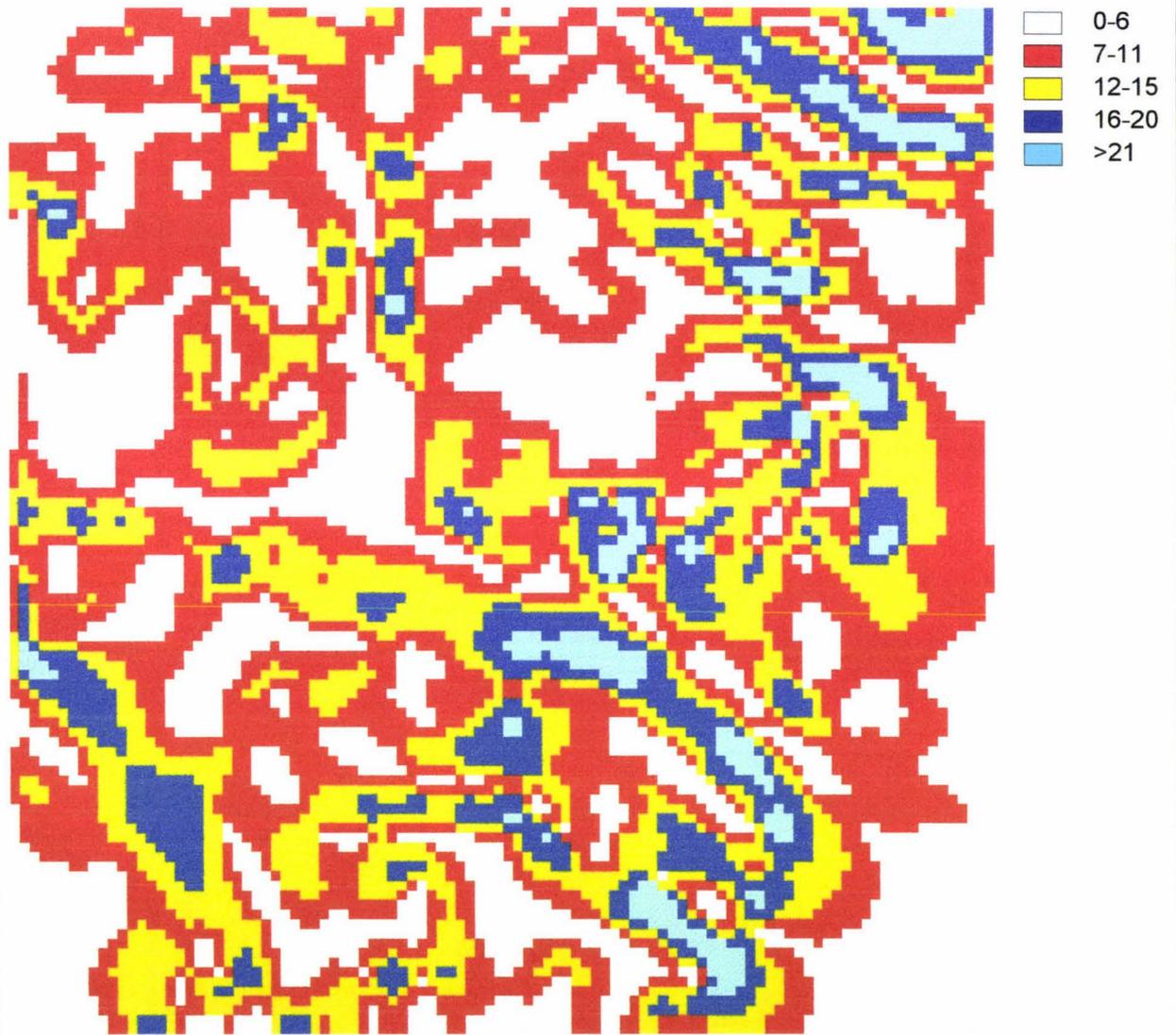
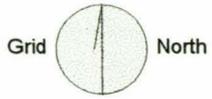


Figure 5.1

Slope Map of the Study Area



- 0-6
- 7-11
- 12-15
- 16-20
- >21



Meters
500.00

5.1.2 Slope Aspect and Hillslope Aspects Units Map

Hillslope aspects units are areas of relatively uniform slope and aspect that are often separated by ridges and streams. Aspect regions, which generally span from stream to ridge, are identified after generalising the aspect map derived from digital elevation data.

A slope aspect map was generated from the DEM image with the following eight geographical directions : Northerly (N), North easterly (NE), Easterly (E), South easterly (SE), Southerly (S), South westerly (SW), Westerly (W), North westerly (NW). Figure 5.3 shows how each actant was determined from the original aspect map which contained values from 0-360 degrees and -1 (flat).

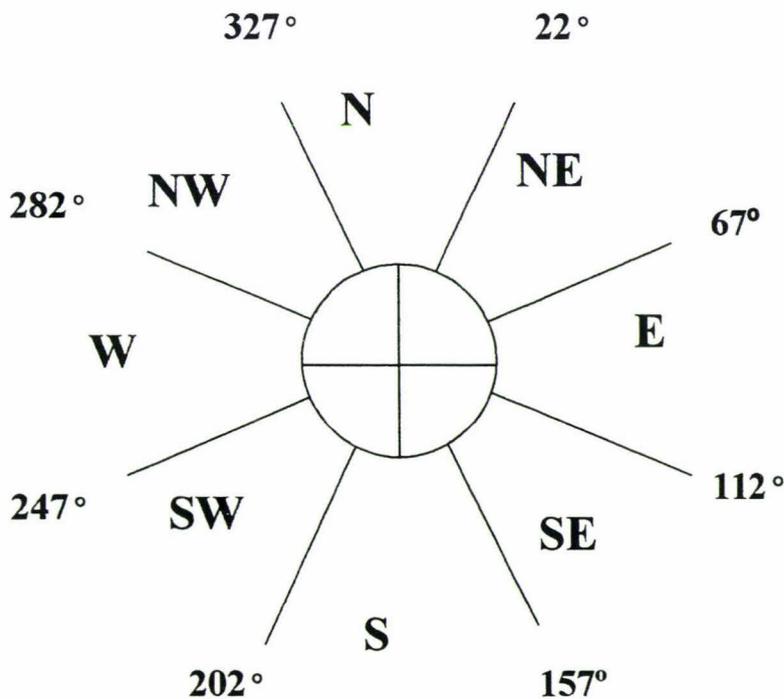


Figure 5.3 Eight Geographical Directions Of Slope Aspect Map

As we can see in Figure 5.4 the aspect classification performs a good first cut of the landscape, regionalising many major land units that stretch from ridge to stream. This classification, however, also produces many regions that are much smaller than typical hillslope aspects units and which need to be dissolved. These regions or individual pixels can be regarded as noise in the map. Some noise is data error introduced in the surface generation process, while other present real topographic features such as quarries or natural potholes.

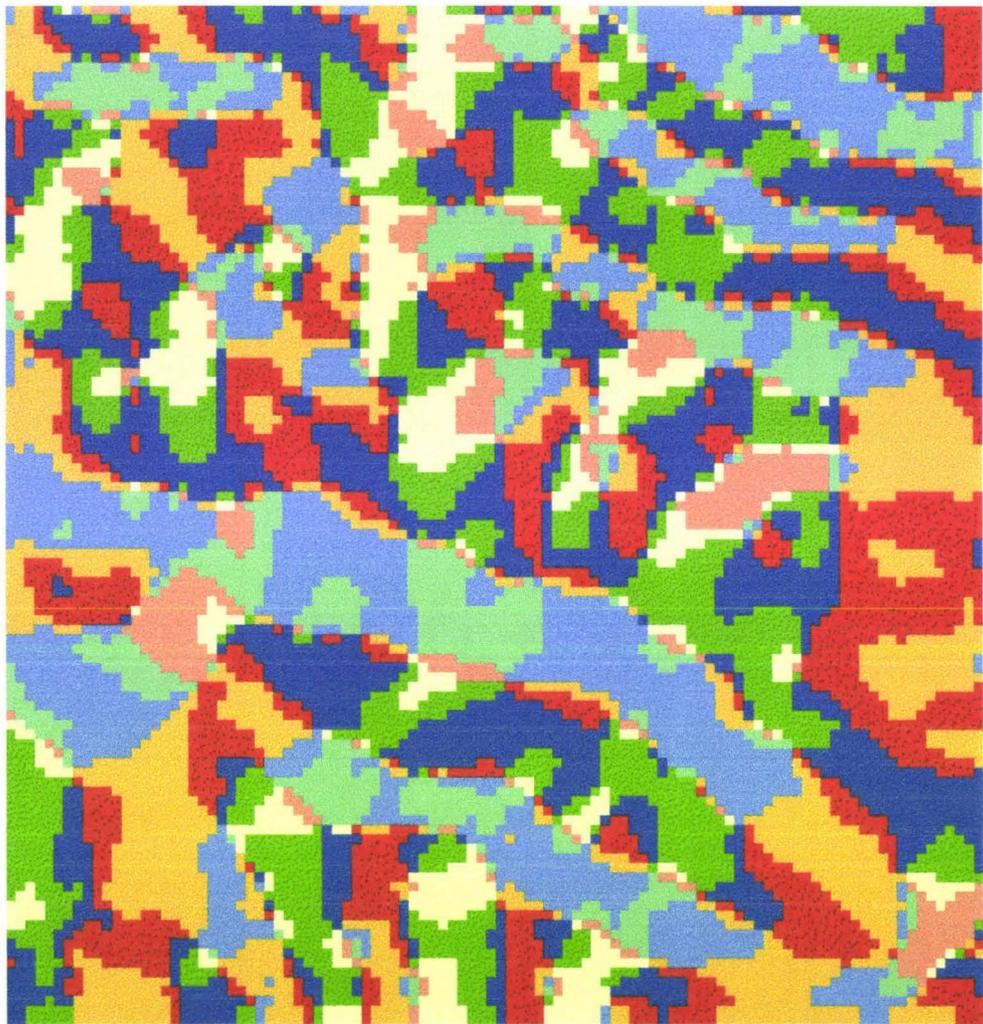
DEMs almost always contain depressions as well which may sometimes appear as noise in the generated slope aspect image.

Having an aspect image with uniform noiseless hillside units was necessary for further analysis. Therefore, the first step was to create an adjusted “noiseless” aspect map.

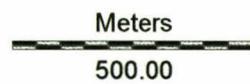
In this study noise was removed by using a smoothing filter on the aspect image. The gentle rolling country (less than 7 degrees slope angle) was classified as slope class one. These areas are not affected by soil slip erosion that generally occurs in areas with a greater slope. Figures 5.5 and 5.7 show the hillslope aspect units map and the distribution of land hillslope aspect units according to their aspects.

The image of vegetation cover and eroded areas(Figure 4.2) was reclassified to generate the image of eroded areas, and then the amount of eroded area was calculated by using AREA Module of Idrisi for Windows. The images of eroded areas and hillslope aspect units were combined using a crosstabulation function to generate an image of eroded area according to hillslopes. Figures 5.6 and 5.8 show the distribution and a map of eroded area according to hillslopes, respectively.

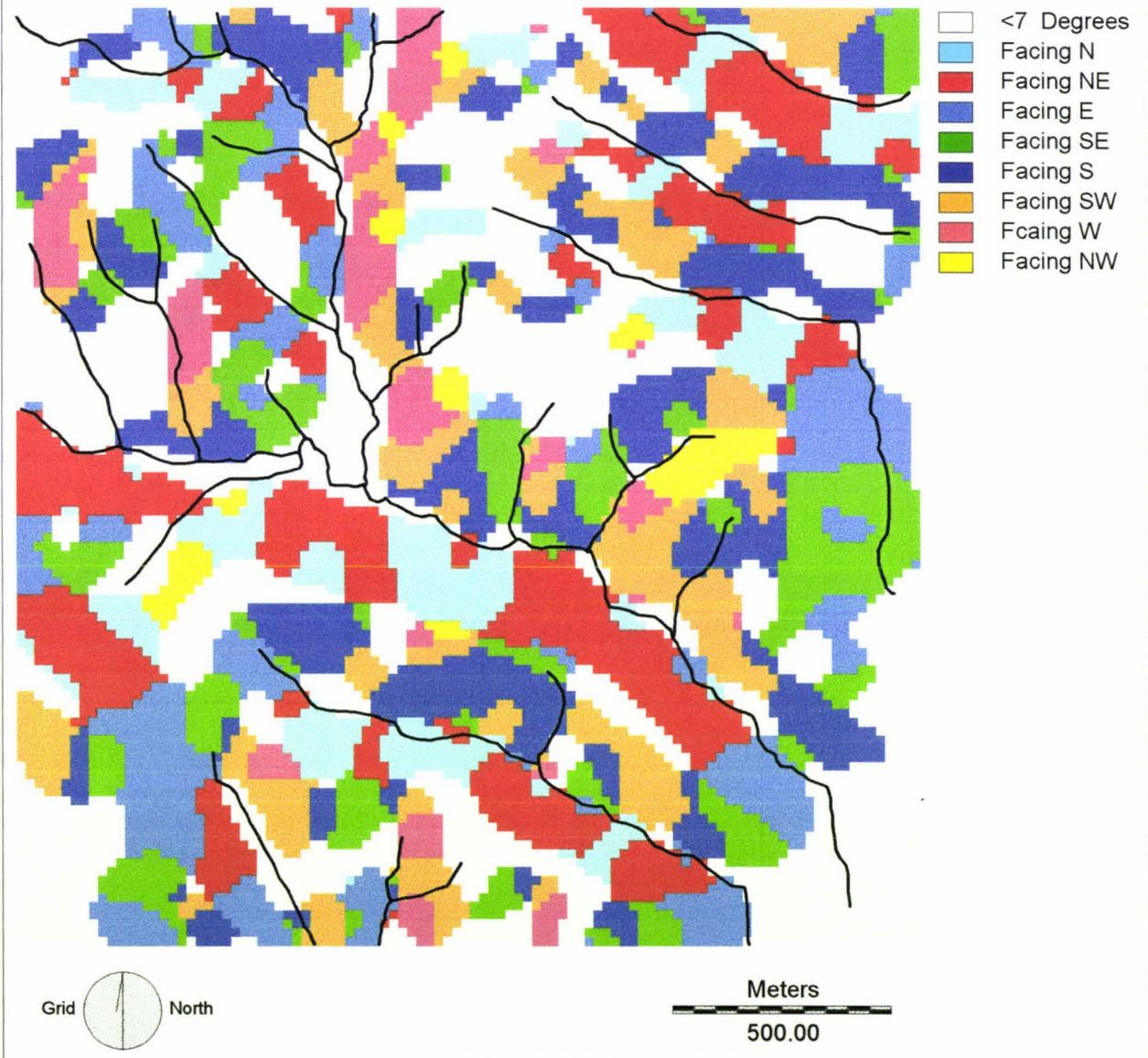
Slope Aspect Map of the Study Area



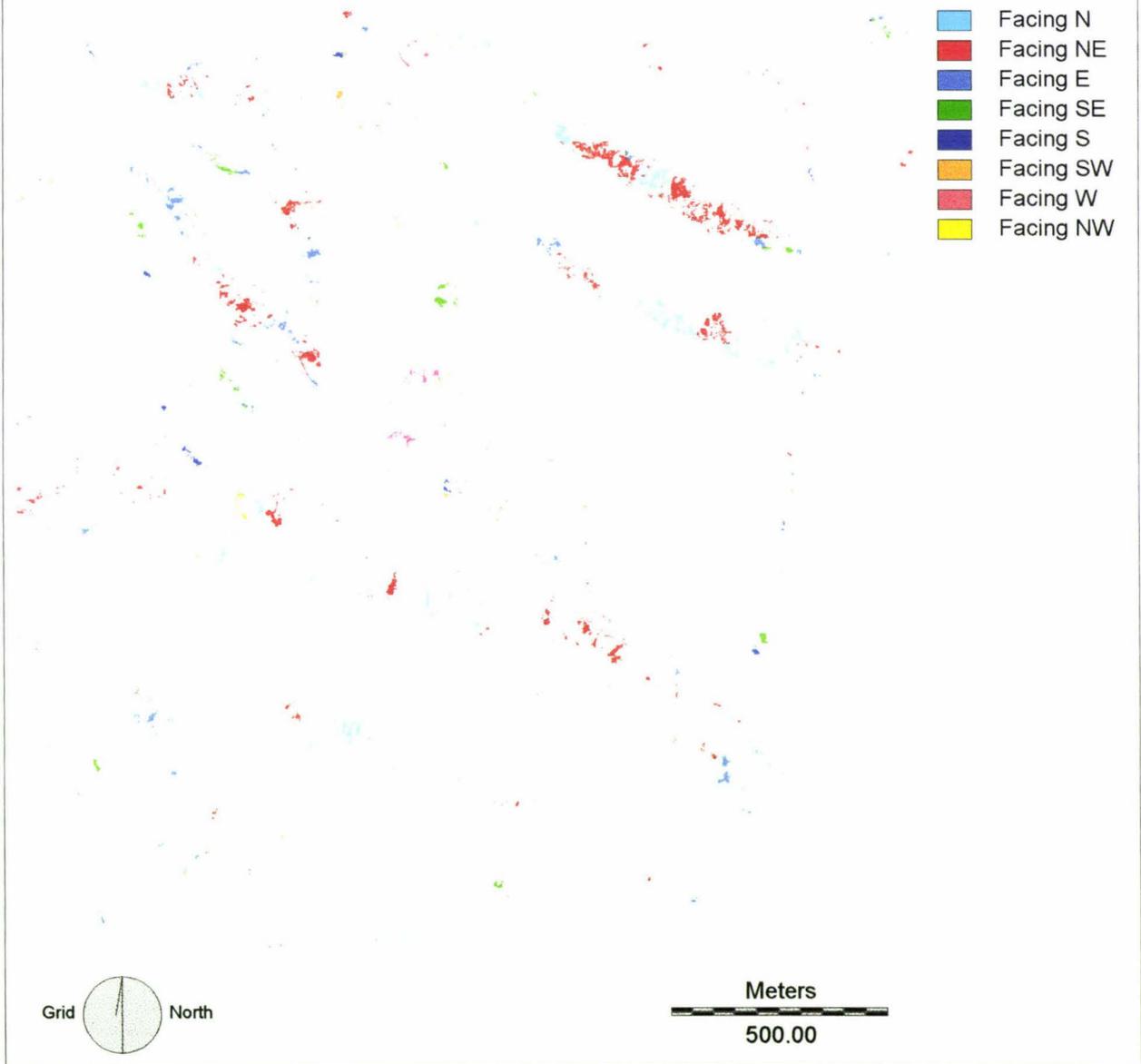
- Facing N
- Facing NE
- Facing E
- Facing SE
- Facing S
- Facing SW
- Facing W
- Facing NW



Hillslope Aspect Units Map of the Study Area



Map of the Eroded Areas According to Hillslope Aspects



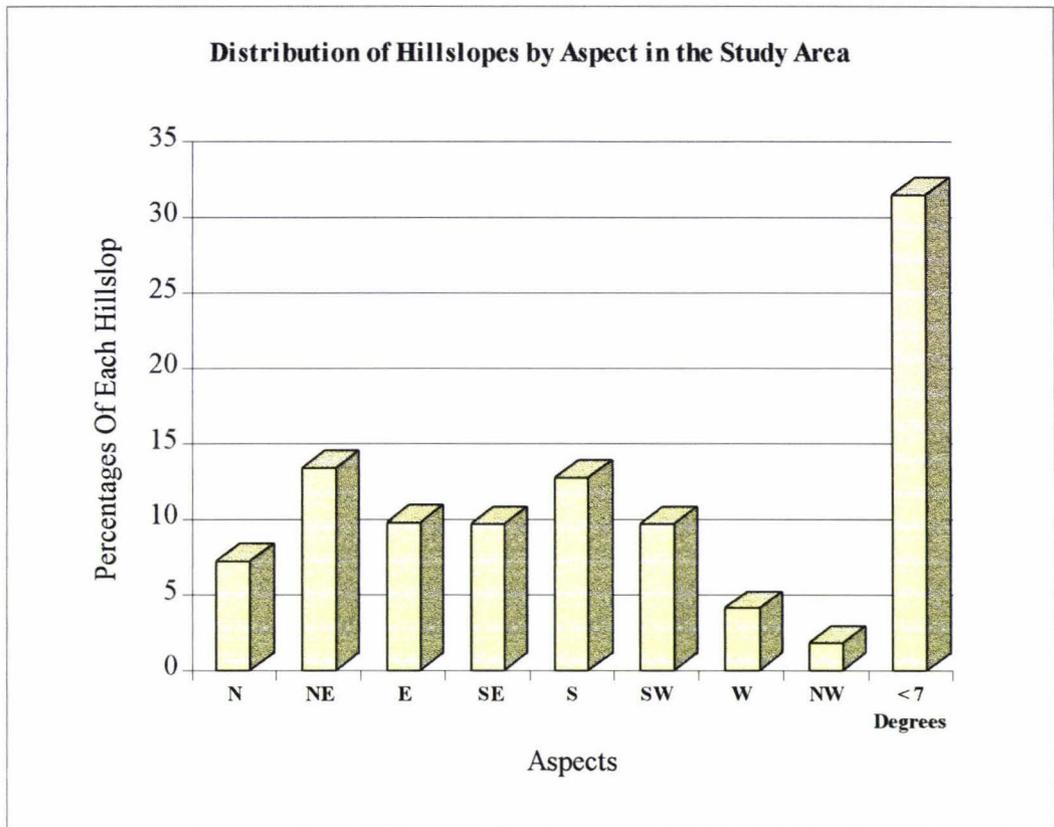


Figure 5.7

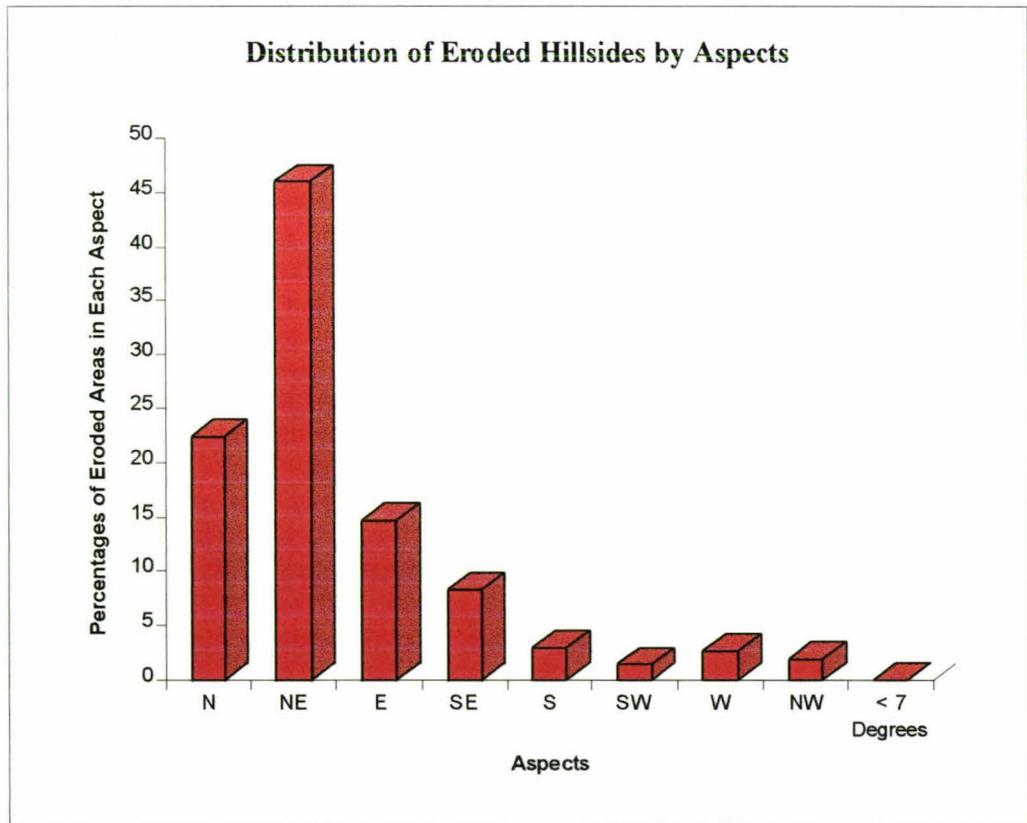


Figure 5.8

5.2 Automatically Derived Sub-Watershed Boundaries, Using a DEM

To check whether the hillslope aspect units are located within an appropriate their watershed or not a technique was developed to delineate the watershed boundaries. By overlaying the boundaries on top of the hillslope aspect units map we can determine the accuracy of the hillslope aspect units.

The ability to delineate watershed boundaries without spending lot of time studying topographical maps or stereo pairs of aerial photographs have always been considered desirable researchers in variety y of studies such as natural resources, hydrology, planning etc.

Computer held digital maps present an opportunity to automate the extraction of catchment characteristics with the resultant benefit of speed, accuracy, standardisation, and also the ability to create new, more meaningful characteristics.

The derivation of catchment characteristics such as, catchment shape, aspect, slope, travel time, and so on, use the two primary information sources contained on topographical maps: contour and drainage lines.

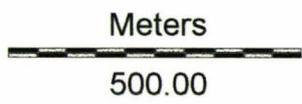
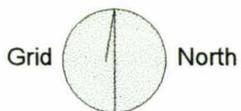
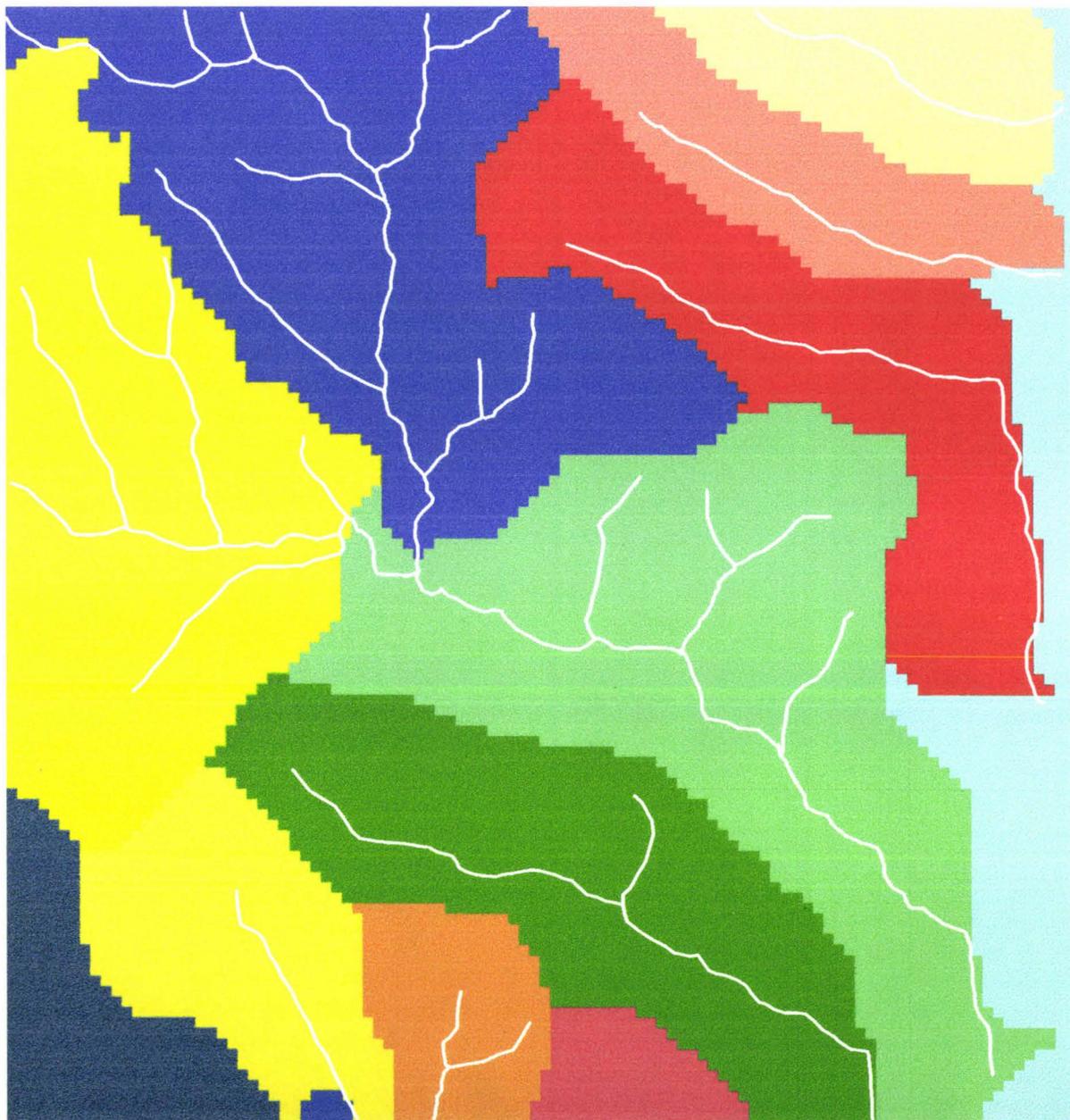
To delineate the sub-watersheds boundaries stream networks were digitised on screen using the scanned aerial photograph of the study area as a backdrop.

At this point in the processing, two data files exist; the Digital Elevation Model , and a vector file of stream networks.

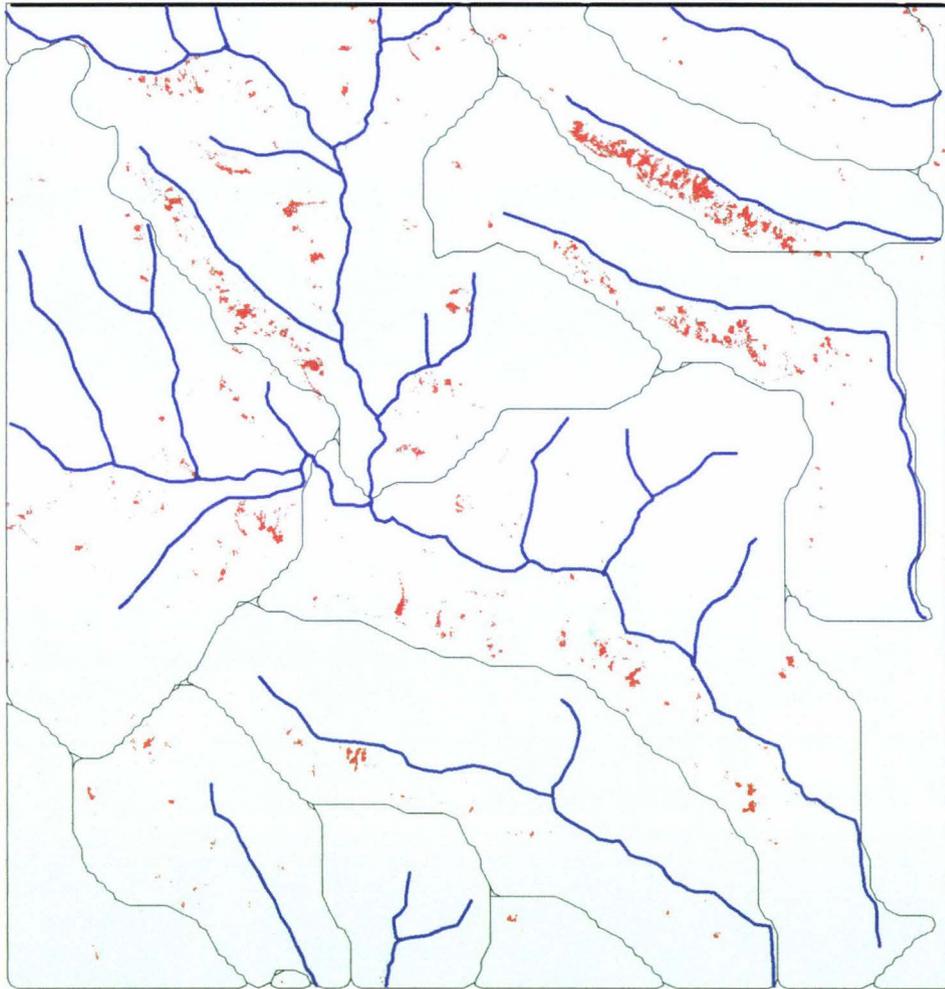
The vector stream networks file was then converted to raster format to determine all the points ultimately flowing to a specified stream by using Idrisi WATERSHED Module. By definition this comprises the catchment of the stream.

Sub-watersheds of the study area are shown in Figure 5.9. As we can see the boundaries are not very smooth. The raster sub-watershed boundaries file was converted to vector format then Idirsi LINGEN Module and low pass filtering was used to smoothing the boundaries. Figure 5.10 shows the final map of the sub-watershed boundaries of the study area.

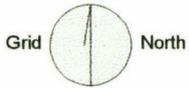
Sub-Watersheds Map of the Study Area



Sub-watersheds and Soil Slips in the Study Area



 Eroded Areas



Meters

500.00

5.3 Effect of Slope Angle and Slope Aspect on Eroded Areas

To investigate whether the eroded areas on hillslopes were a function of slope angle or not, the slope and hillslope unit maps were combined using a crosstabulation function. Figure 5.11 shows the distribution of hillslopes according to both aspect and slope class. Most of the hillslopes can be described as rolling to strongly (7-15 Degrees) but those which are steep to very steep (> 16 Degrees) tend to be dominated by north and northeast-facing aspects. The hillslopes are most evenly distributed within the slope classes 2 and 3 (7-15 Degrees).

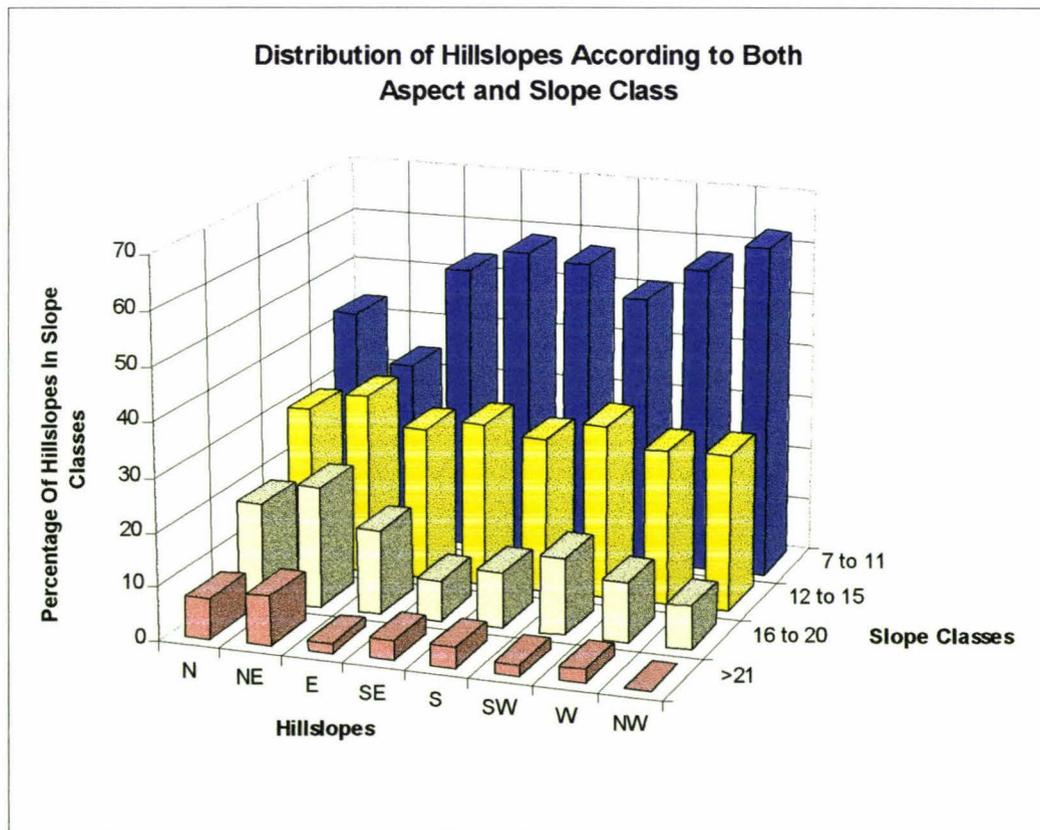


Figure 5.11

To determine the effect of slope angle and slope aspect on eroded areas, the distributions of eroded areas per slope class were calculated using the crosstabulation function between the eroded area and different slope classes. Figure 5.12 shows those results. The eroded areas mostly occurred on N & NE facing hillslopes. It must be considered that these aspects are also the most common aspects for the steeper slopes.

The hillslope aspect units that are affected by soil slip erosion were identified by using Group module of Idrisi and then the sub-watershed boundaries was dropped on top of it to illustrate their positions in the sub-watersheds. Figure 5.13 shows the hillslope aspects units that are affected by soil slip erosion within their watersheds.

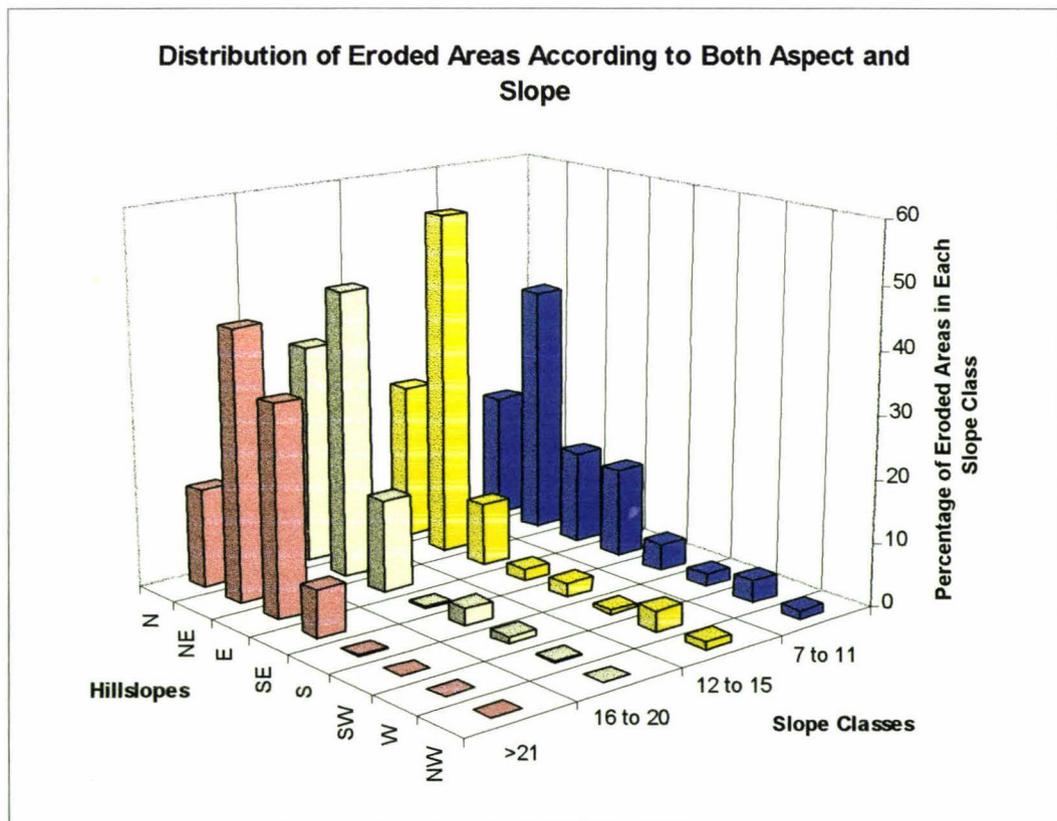
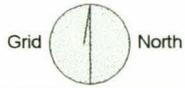
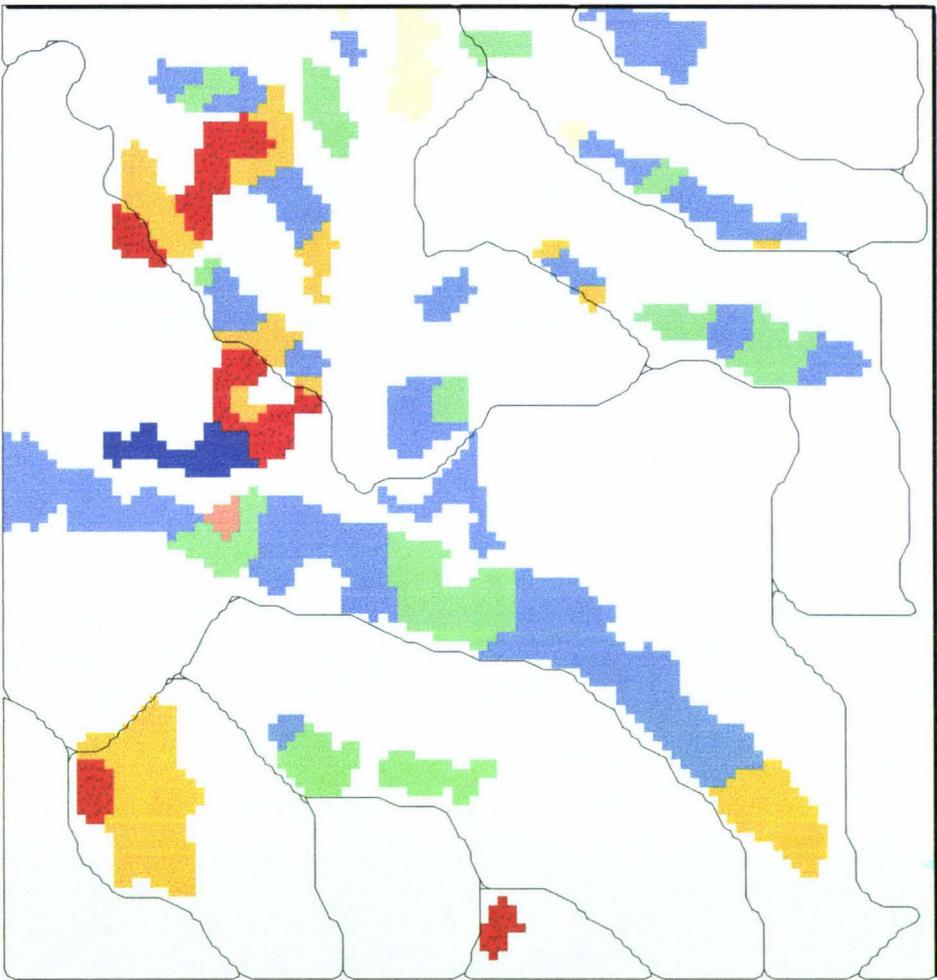


Figure 5.12

Hillslope Aspect Units Which Are Affected by Soil Slip Erosion



Meters
500.00

The distributions of slope classes in the study area and eroded area in slope classes are showing an existence of a similar rate of distributions. It shows that with increasing the slope classes the amount of the eroded area decreases and the same thing is apply for distribution of slope classes in the study area. By calculating the percentage of eroded areas in each slope class it was proven that the rate of the soil slip erosion is more likely depending to the susceptible rock types to soil slip erosion rather than slope angle. The percentage of each slope class that is eroded is similar, but the percentage of slope classes in the study area decreases as the slope gradient increases. These results have proved we have the same rates of erosion in different slope classes in this area.

Figure 5.14 shows the distribution of slope classes in the study area and Figures 5.15 and 5.16 show the distribution of eroded areas in slope classes and the percentage of eroded area in each slope class.

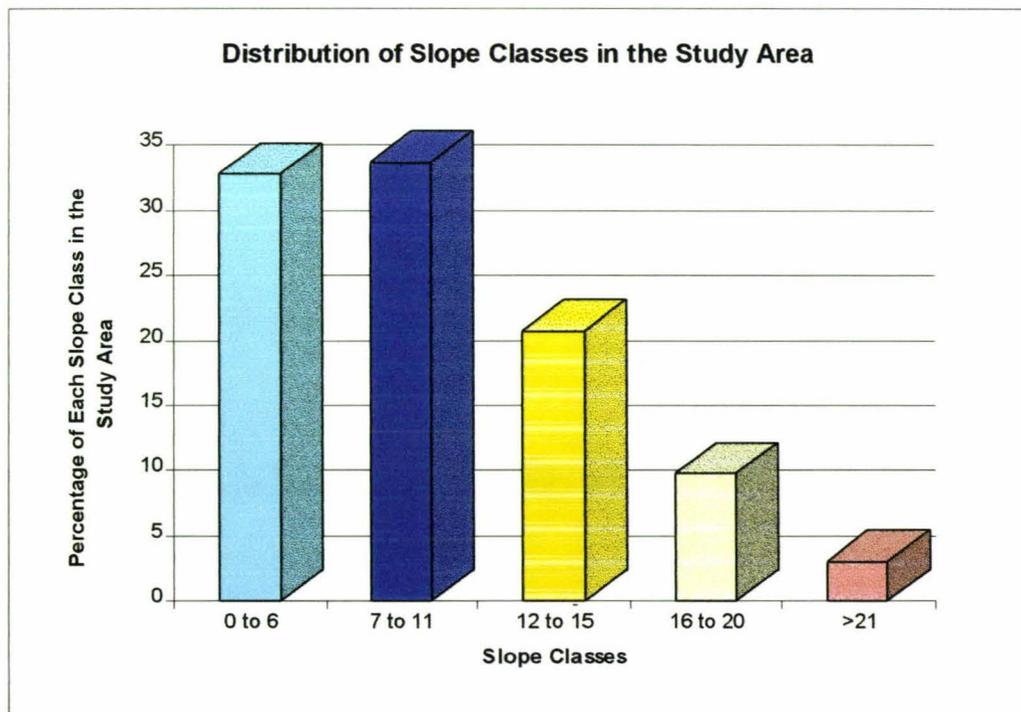


Figure 5.14

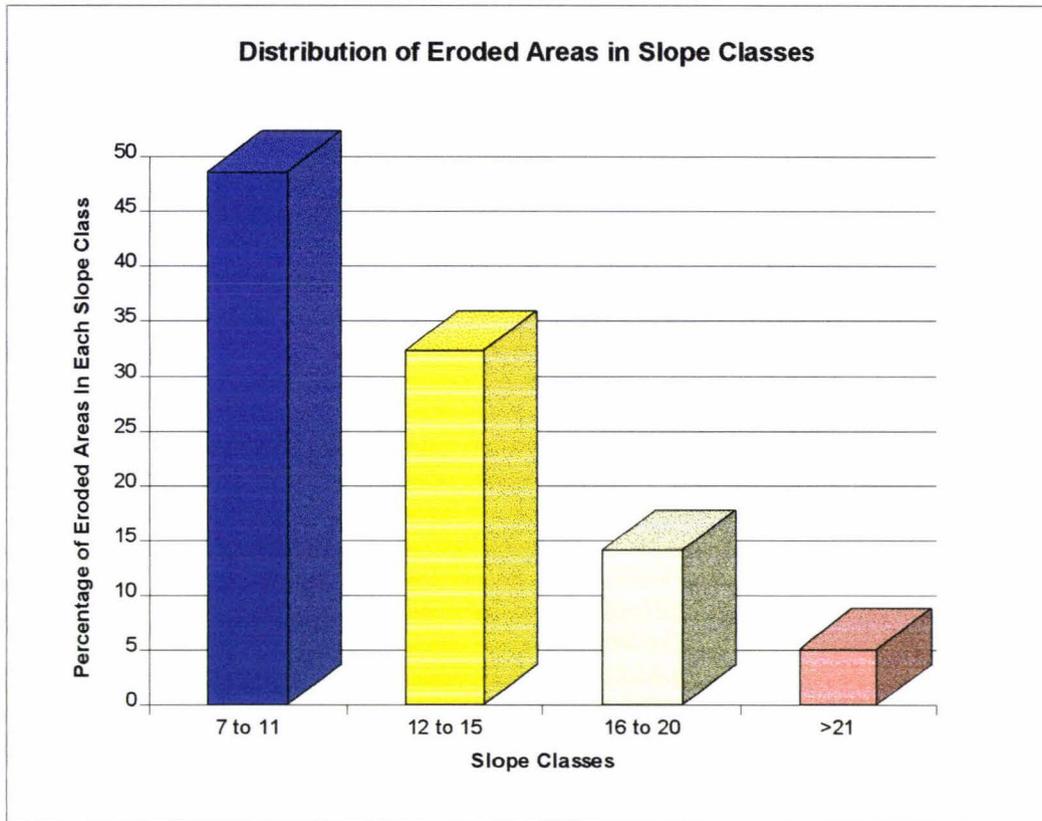


Figure 5.15

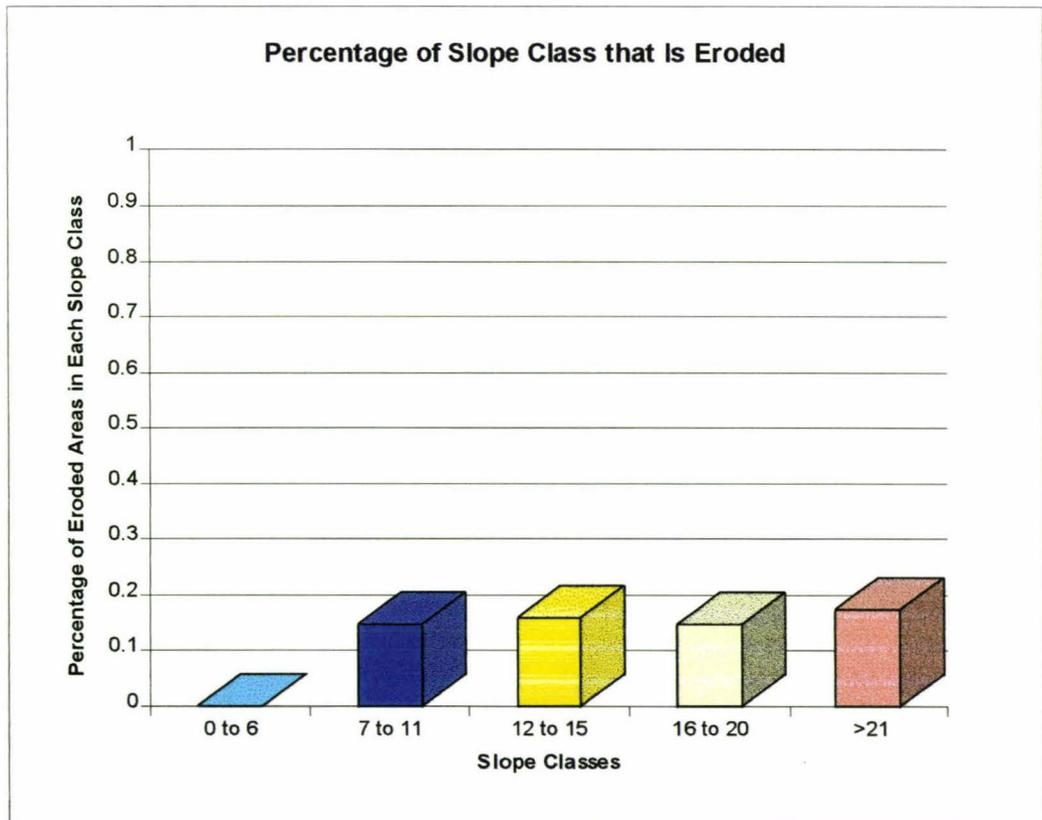


Figure 5.16

5.4 Effect of Land Management on Soil Erosion Control

A vegetation cover map of the study area was delineated from the aerial photograph by using on screen digitising and an unsupervised classification technique. Figure 5.17 shows the percentage of different land management practices in the study area. Nearly 70 % of the area is in pasture and 14.4 % in native bush, 3.4 % is in exotic forest and finally 12.6 % consists of pasture together with pace planted conservation trees.

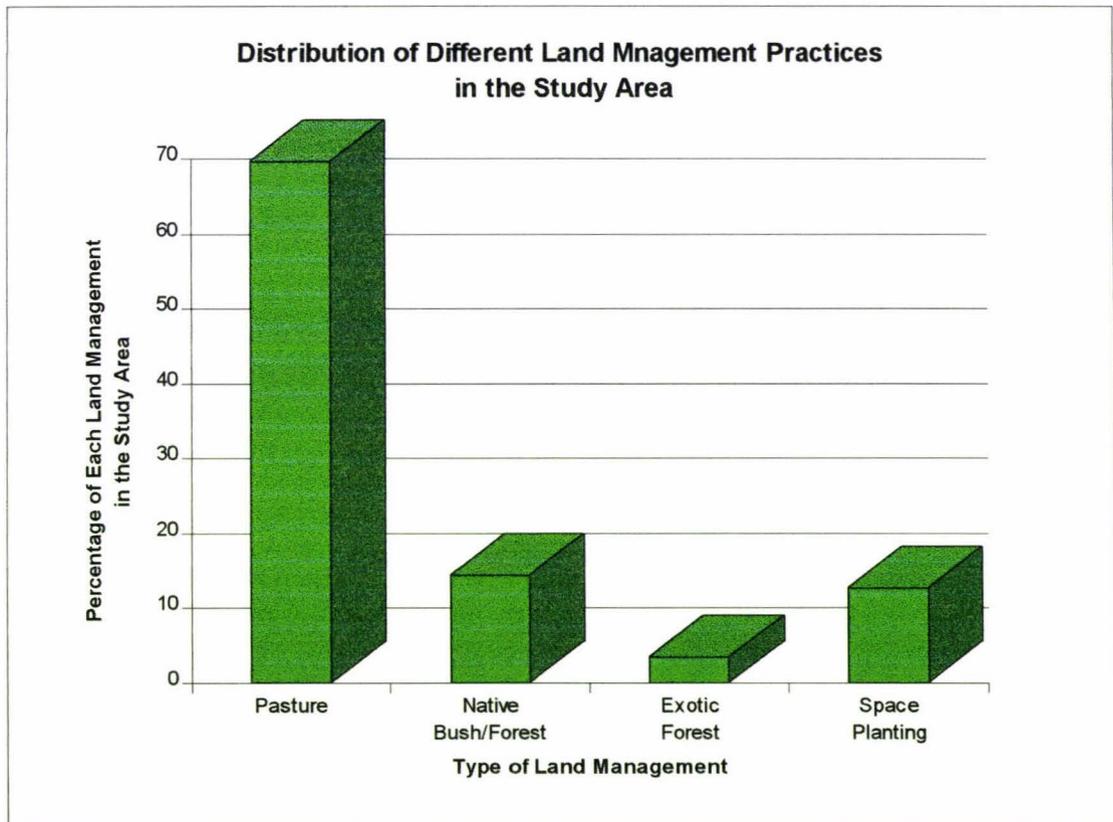
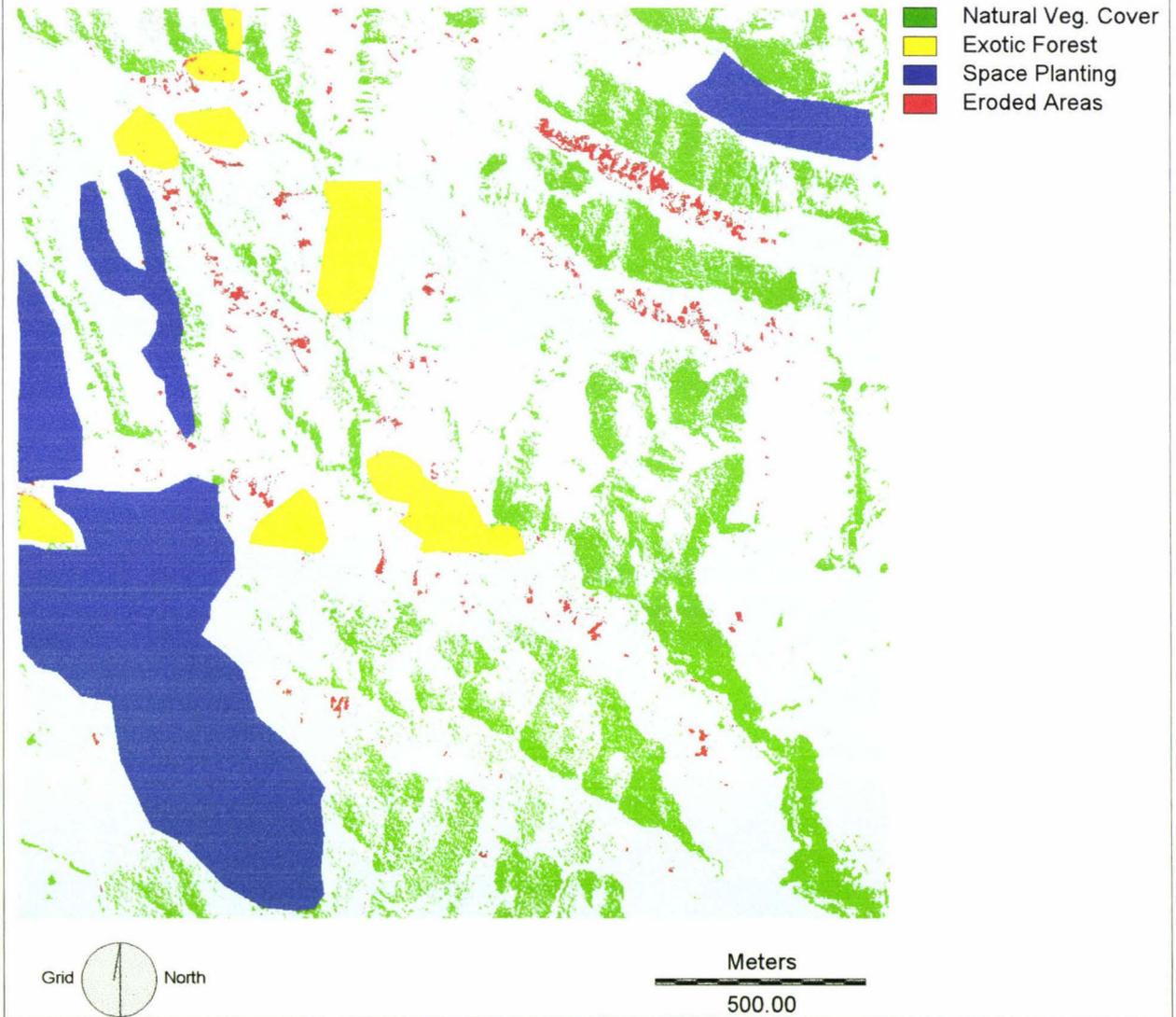


Figure 5.17

Vegetation Cover Map of the Study Area



After comparing the vegetation map and the eroded areas map, Figure 5.19 was calculated. There is no erosion in areas which are covered with the natural vegetation cover. Nearly 95 % of erosion has occurred in pasture, 4.1% in space planted areas, and 1.3 % in exotic forests.

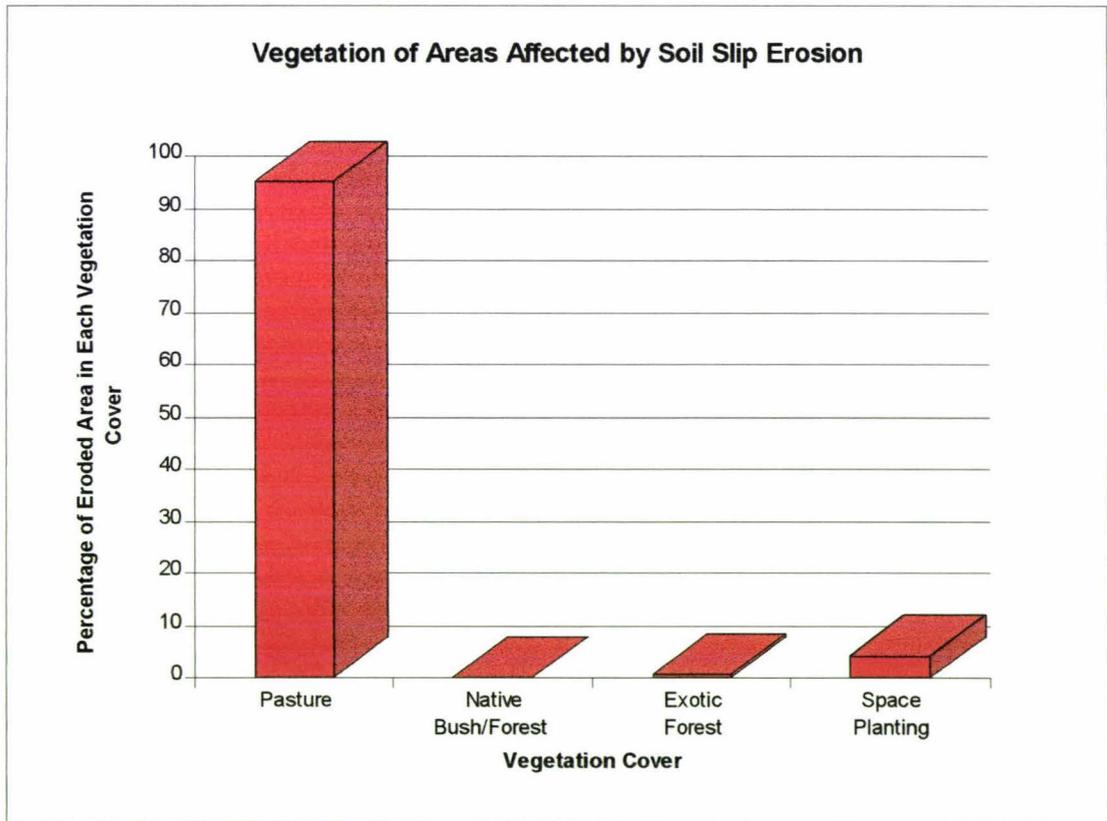


Figure 5.19

The percentage of natural vegetation cover on different aspects was also calculated. Figure 5.20 shows that the natural cover predominates on S & SW facing slopes. This may be because of soil moisture differences within different aspects. The dry N & NE faces and the relatively damp S & SW faces provide the greatest contrast in soil moisture status. The much slower rate at which the S & SW aspects dried out in summer compared to other aspects could be a reason for increased reversion to native scrub and forest here.

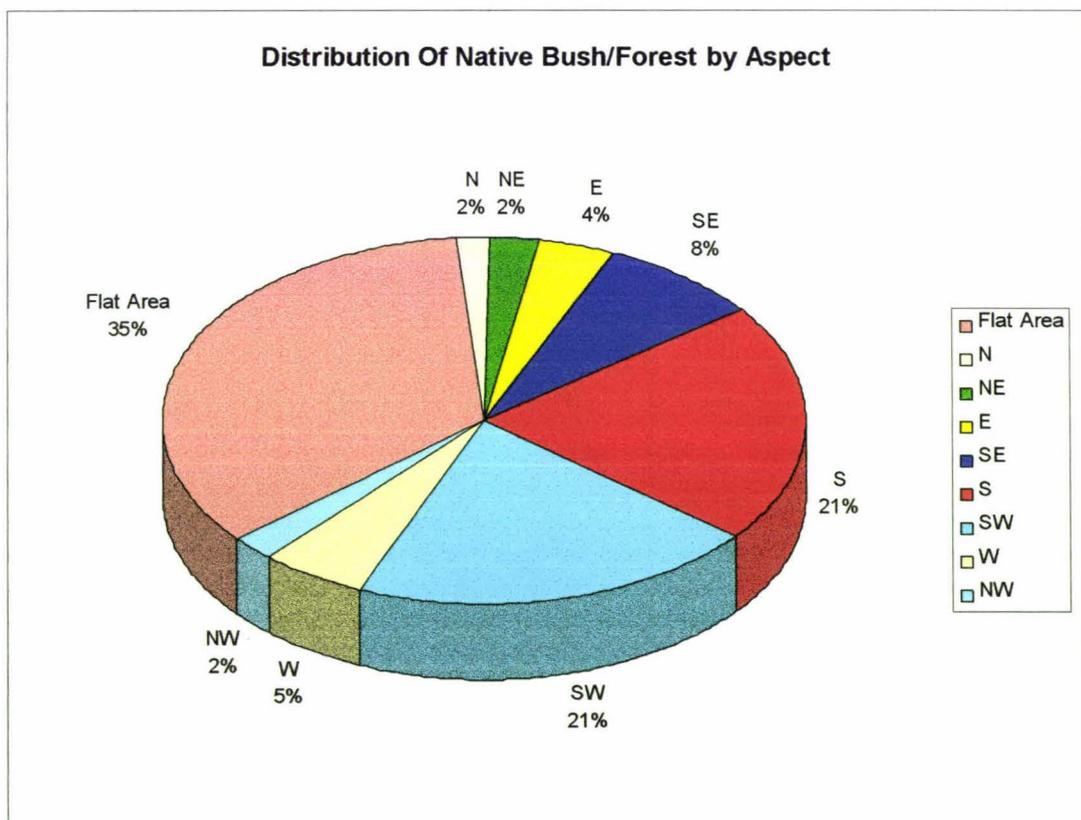
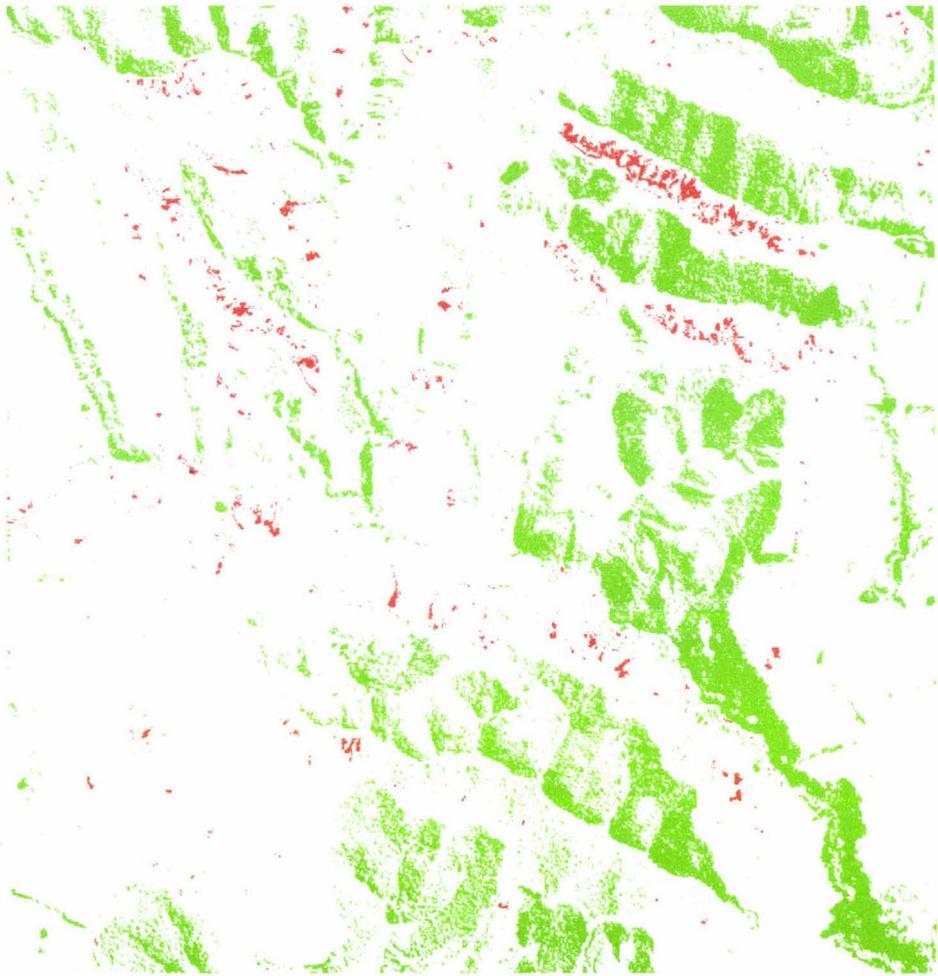


Figure 5.20

Native Bush Cover Map



- Natural Veg. Cover
- Eroded Areas



Meters
500.00

5.5 Summary of Results and Discussion

Most eroded areas have occurred on hillslopes that face north-easterly (NE) and north (N) directions.

The results show that the aerial extent of soil slipping is similar in different slope classes.

The important factor which influences slip erosion in this area is assumed to be the lack of deeply rooted vegetation, which can prevent the soil from slipping.

The percentage of natural vegetation cover on different aspects was shown that the natural cover predominates on S & SW facing slopes.

This may be because of soil moisture differences within different aspects. The dry N & NE faces and the relatively damp S & SW faces provide the greatest contrast in soil moisture status. The much slower rate at which the S & SW aspects dry out in summer compared to other aspects could be a reason for increased reversion to native scrub and forest here.

Other investigations which have been done in the Pohangina Region have shown the critical slope angle is 15 degrees.

The results of this study show that the extent of erosion is similar in all slope classes.

Analysis of the land management practices showed that the areas that are under pasture were affected much more than other vegetation covers by soil slip erosion. Also the areas that were covered with deeply rooted vegetation cover such as native bush, exotic forest and spaced tree planting were more resistant to soil slip erosion mainly because of the roots capability to hold the soil. It is suggested that tree planting be used

as a soil conservation measure for those areas that are in danger of soil slip erosion.

The technique used to map hillslope aspect units and extract sub-watershed boundaries illustrates a relatively simple method for accomplishing these maps. The resulting maps are realistic and give a complete subdivision of watersheds and landforms.

The methods used are more efficient and cost effective than manual methods. They can be used to improve the current land management and bring attention to the hillslopes which are more susceptible to soil slip erosion for further soil conservation practices.

5.6 Analysis of the Pohangina Region

5.6.1 Hillslope Aspect Units Map of the Area

The techniques described earlier were used to generate similar maps of the Pohangina region. Figures 5.22 and 5.23 show the distribution of slope classes and the slope map of the Pohangina region. Figures 5.24 to 5.26 show the hillslope aspect units map and distribution of the hillslopes in slope classes and in the study area.

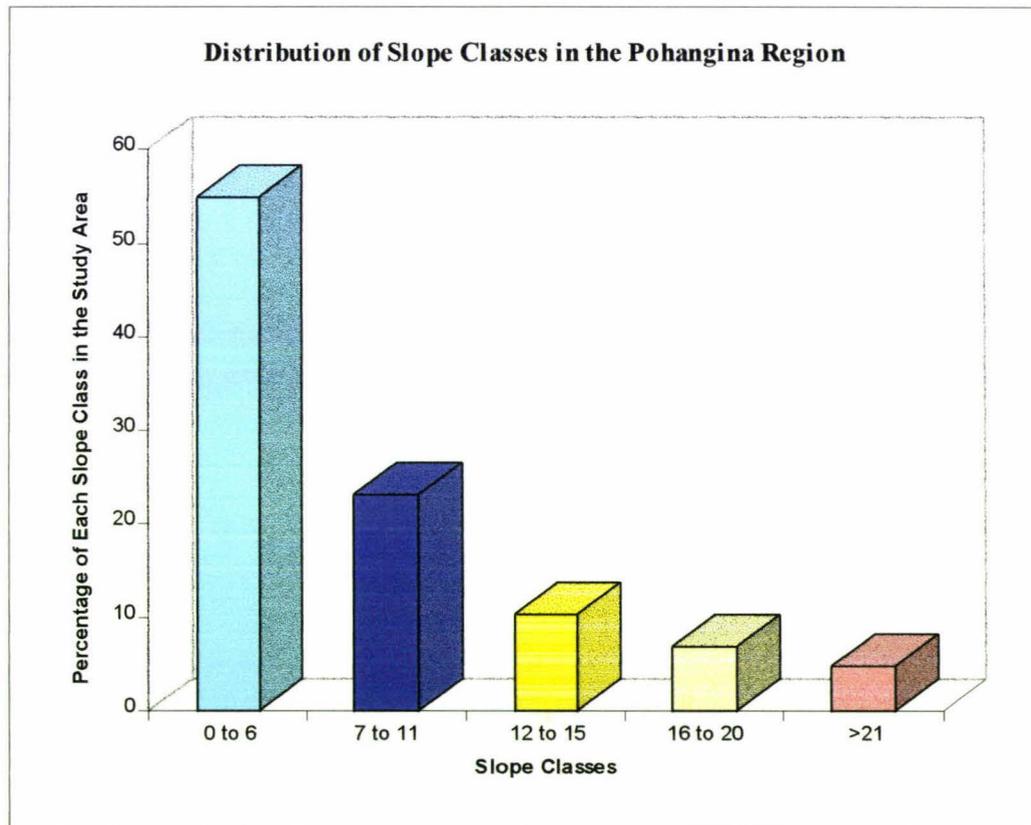
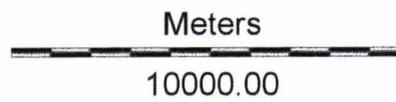
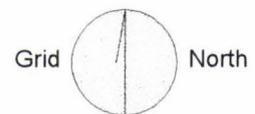
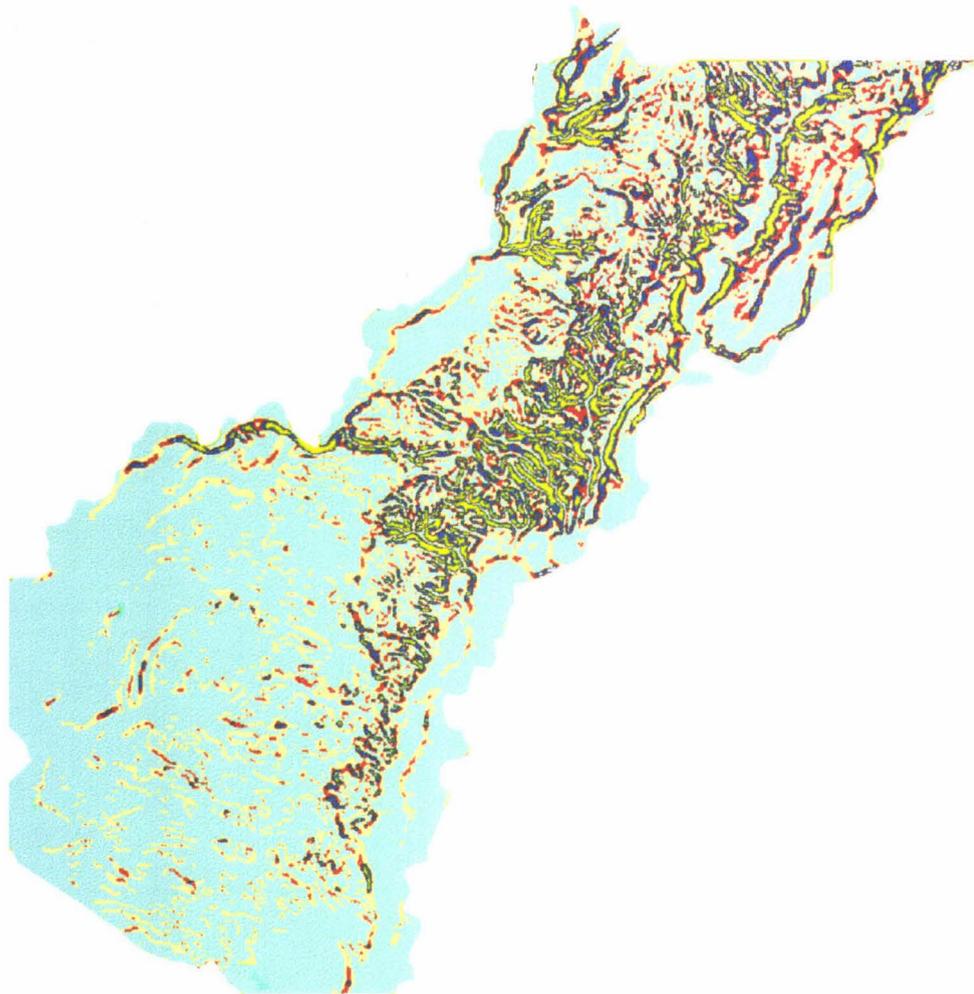


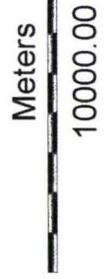
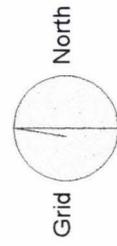
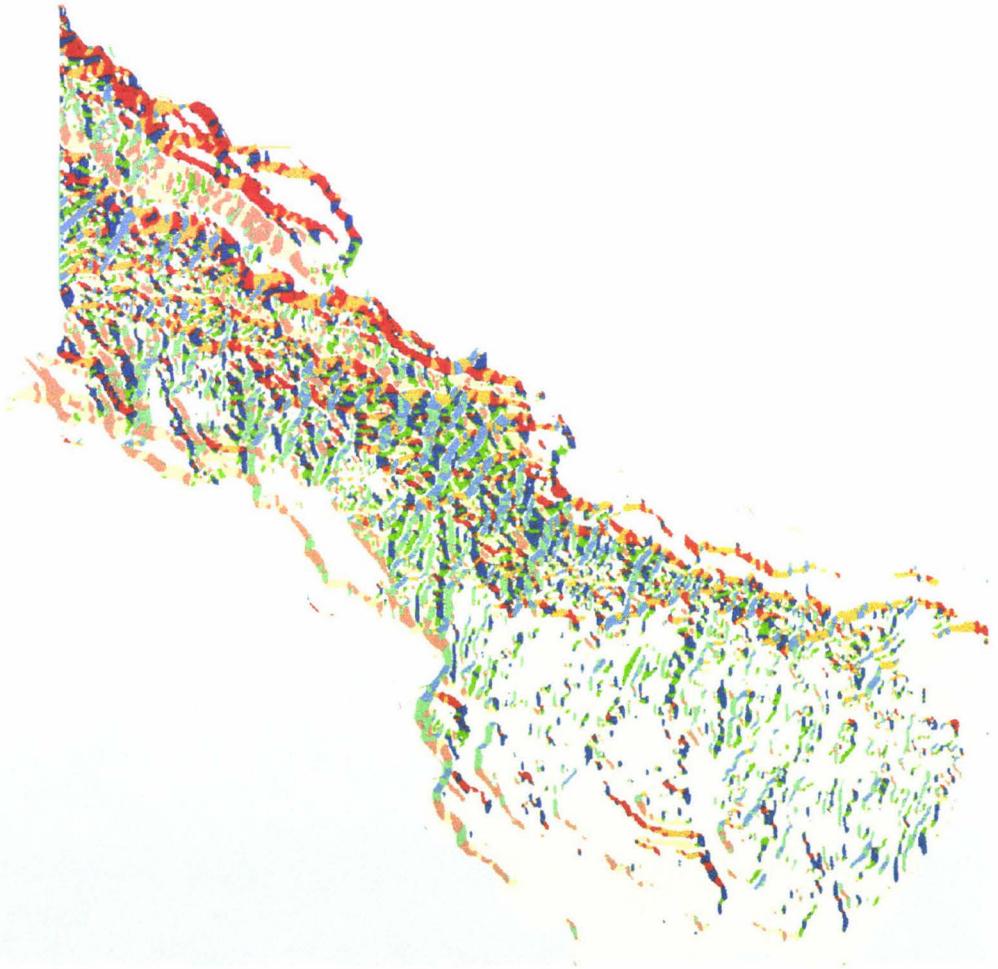
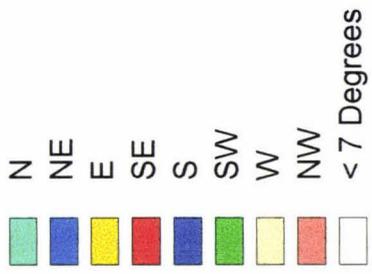
Figure 5.22

Slope Map of the Pohangina Region

- 0 to 6
- 7 to 11
- 12 to 15
- 16 to 20
- >21



Hillslope Aspects Map of the Pohangina Region



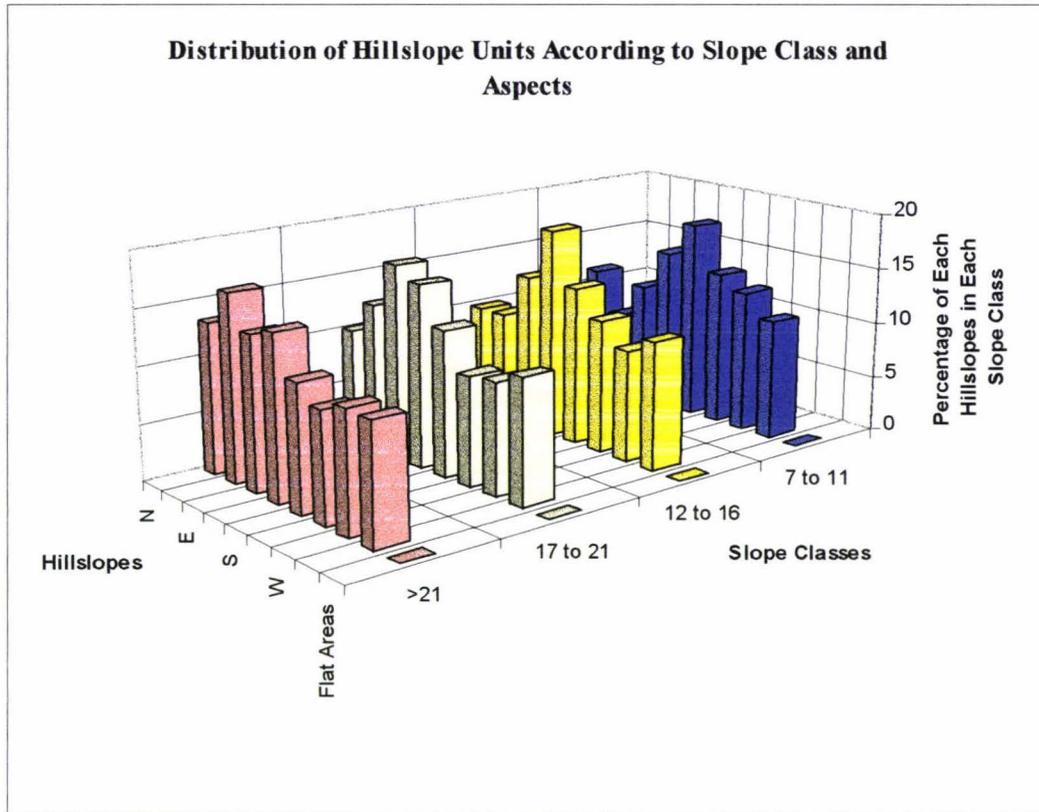


Figure 5.25

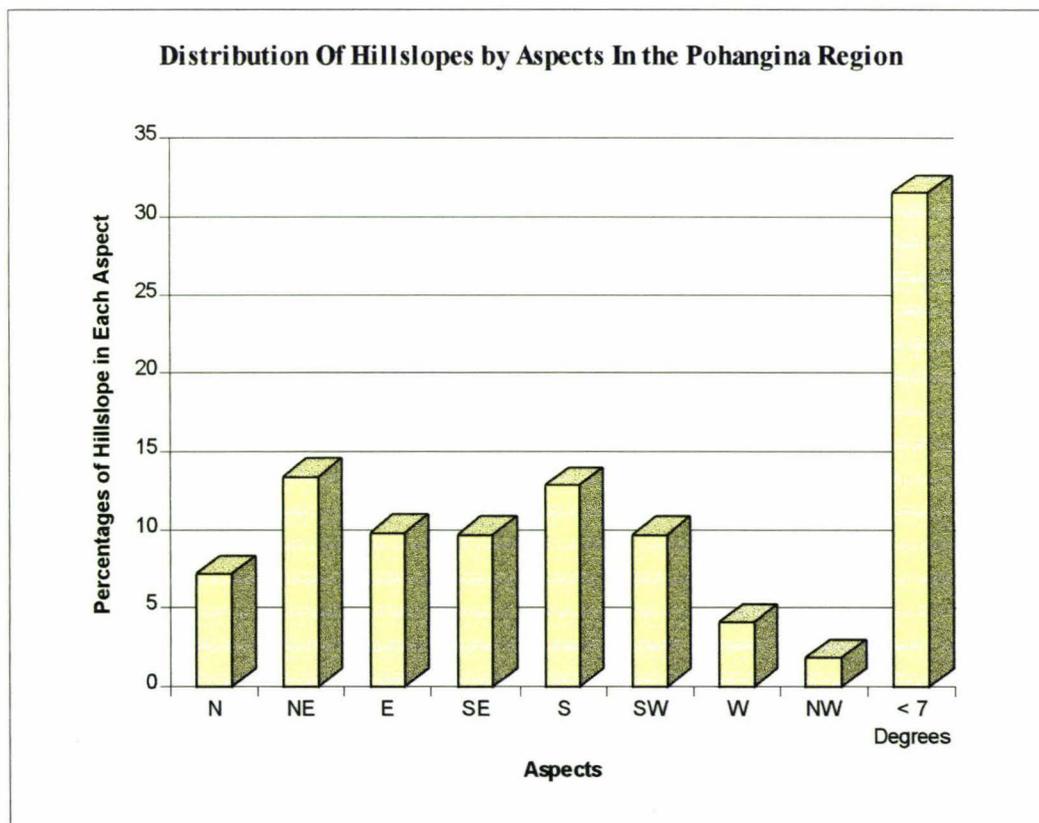


Figure 5.26

5.6.2 Generating A Map of the Areas Most Susceptible to Soil Slip Erosion

5.6.2.1 Areas Susceptible to Erosion

The underlying lithology in the study area and over the much of the Pohangina region is geologically very young and consists mainly of loose unconsolidated Castlecliffian and Haweran sands and silts.

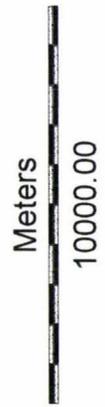
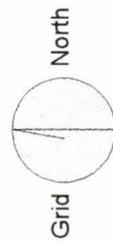
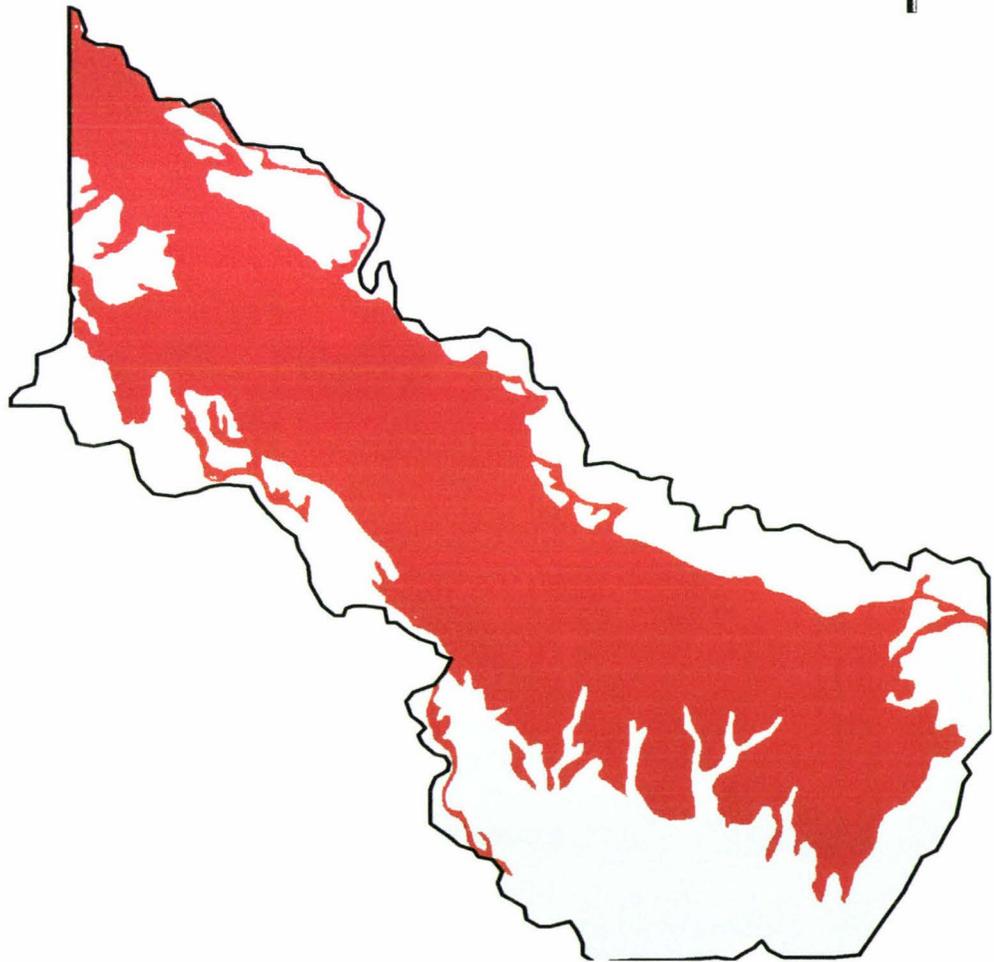
These sands are young and unconsolidated. This means that they have not yet had time to lithify. As the Castlecliffian marine sands have never been deeply buried, they are still soft and loose. Therefore, water easily infiltrates the sands, due to their very porous nature.

Castlecliffian rocks in the Oroua and Pohangina Valleys are predominantly sands interbedded with laminated siltstones. Occasional conglomerate bands and pumice bands also occur in marine sequences or in much dissected high terraces.

These areas with susceptible rock types such as Unconsolidated sands, Loess and any combination of these with other rock types were extracted from the NZLRI data base information using the DATABASE QUERY function in Idrisi. Figure 5.27 to 5.29 show the map of the rock types susceptible to soil slip erosion and their distributions according to hillslopes and slope classes in the Pohangina region.

Map of the Rock Types Susceptible to Soil Slip Erosion

 Susceptible Rock Types



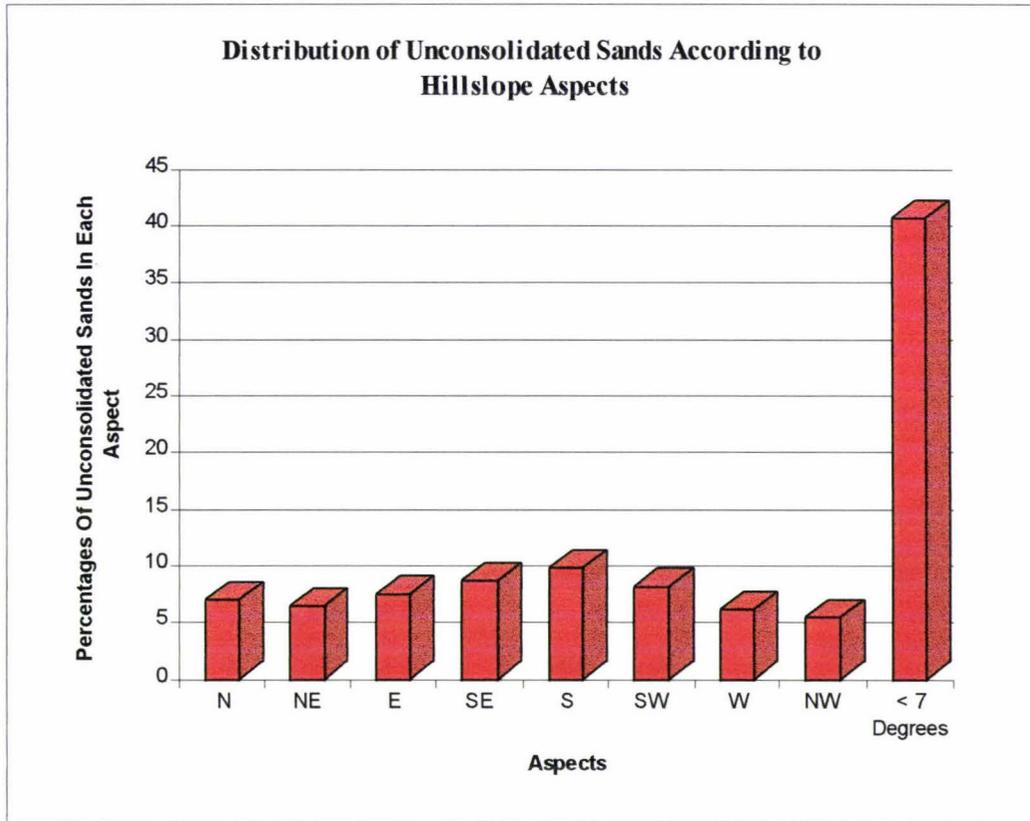


Figure 5.28

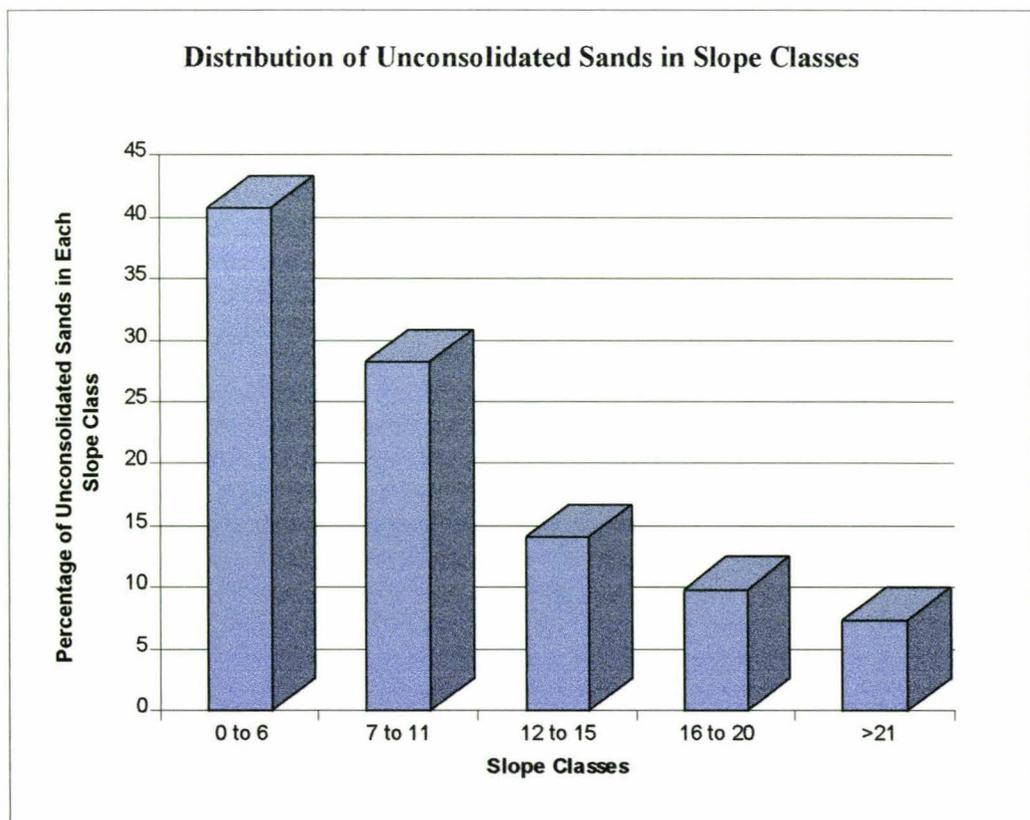


Figure 5.29

5.6.2.2 Deeply Rooted Vegetation Cover And Its Distribution

A Spot satellite composite image of the area was classified using supervised classification to generate map of forest and native bush. Figure 5.30 shows the percentage of the deeply rooted vegetation cover in the different slope classes. Figure 5.31 shows the map of the deeply rooted vegetation cover in the area. Ninety percent of the Pohangina region is not covered with deeply rooted vegetation cover and 80 percent of the forest and bush is found on the unconsolidated sands. The areas with deeply rooted vegetation cover on rock types susceptible to erosion were identified and excluded from further calculation.

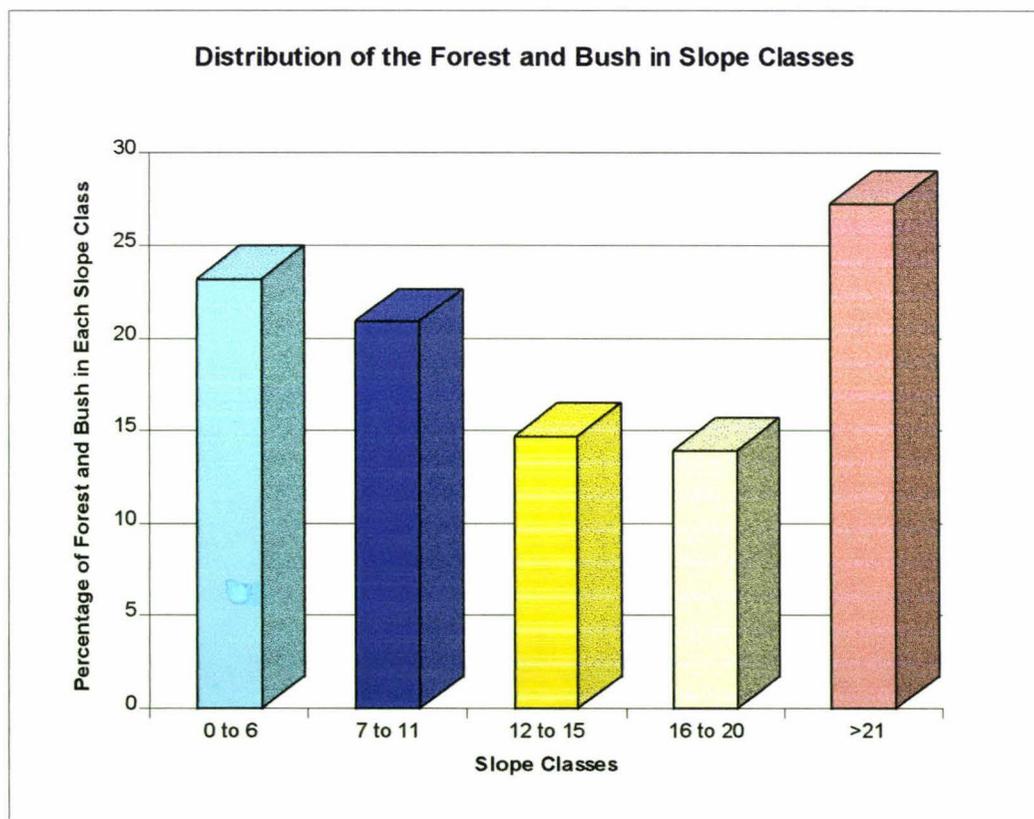
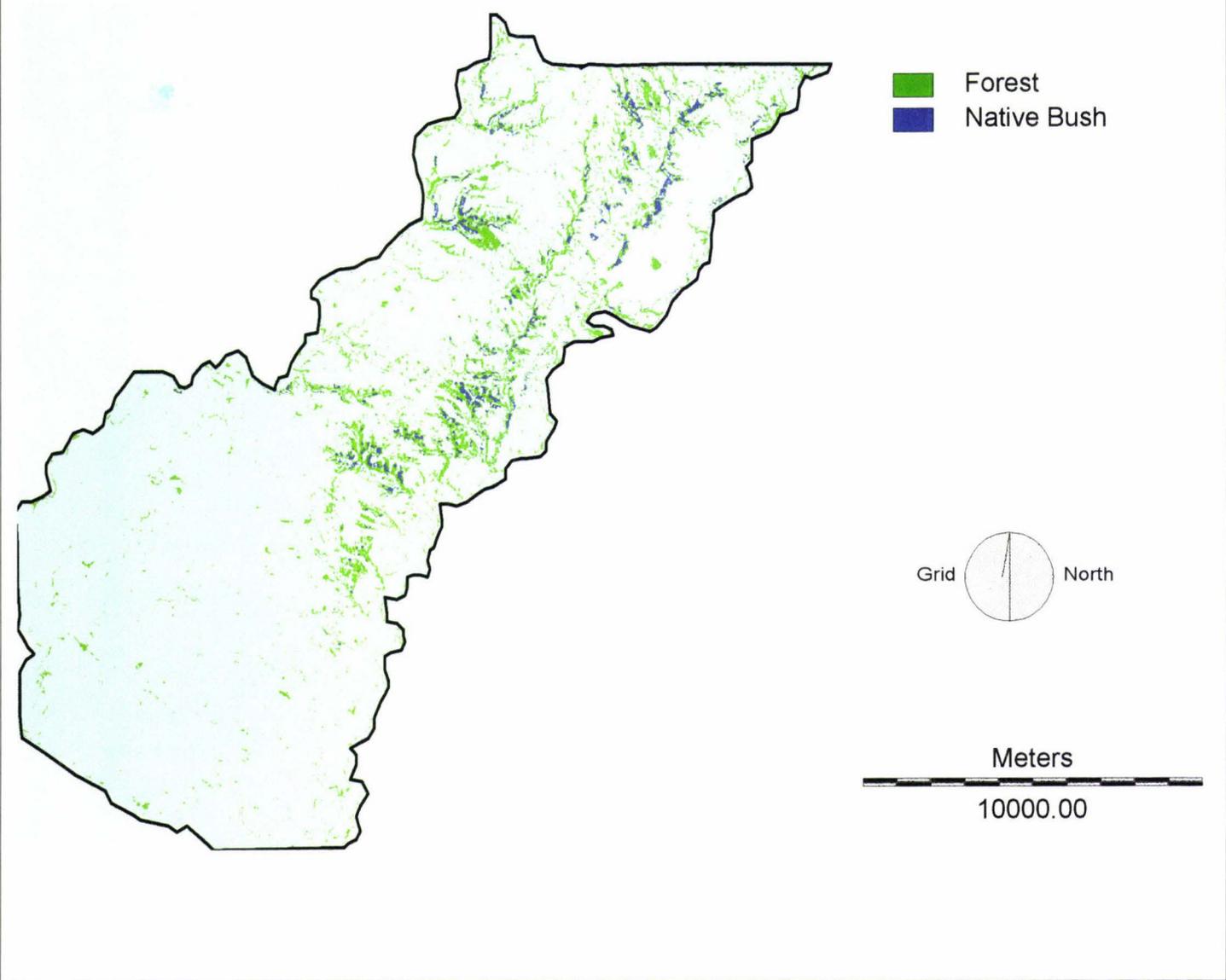


Figure 5.30

Map of the Deeply Rooted Vegetation Cover of the Pohangina Region



5.6.2.3 Identifying The Areas Most Susceptible To Soil Slip Erosion.

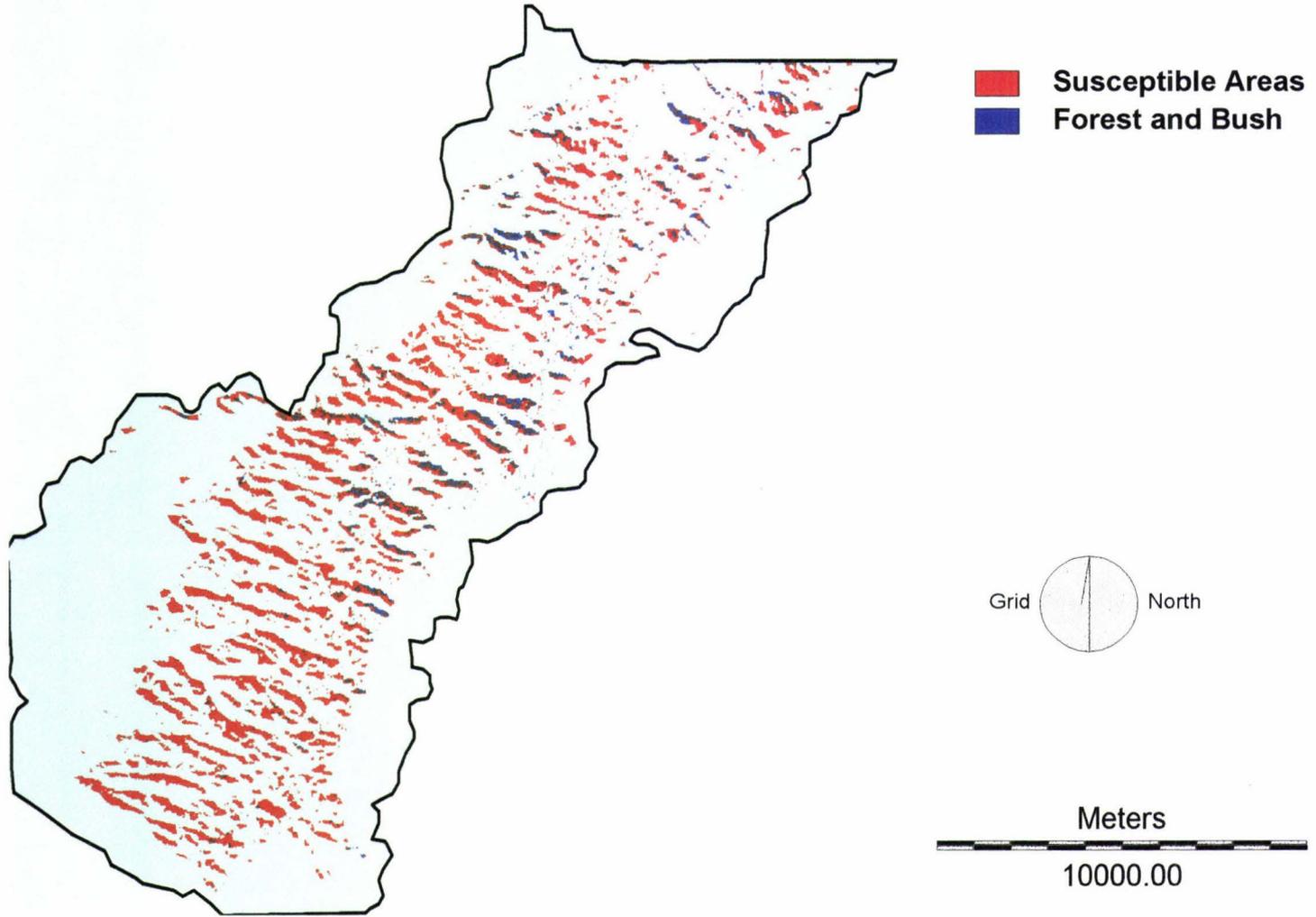
The results of the earlier analysis showed that N & NE aspects are more susceptible to soil slip erosion. It is also known which rock types are most susceptible to erosion. A map of the areas most susceptible to slip erosion was generated by using the RECLASS and OVERLAY functions of Idrisi.

The resulting image represents the areas with N & NE aspects, on unconsolidated sands and not covered with deeply rooted vegetation cover.

The first step in generating the map was reclassifying the hillslope aspect map by choosing the areas which were facing to N and NE directions. This image was then combined with the mask of rock types susceptible to erosion to generate an image of the areas most susceptible to soil slip erosion. For the last step, the areas covered with deeply rooted vegetation cover were excluded to generate the final image of the areas most susceptible to soil slip erosion.

Figure 5.32 and 5.33 show the areas most susceptible to soil slip erosion and their distribution in the Pohangina region. These are the areas which should be targeted for possible changes in land uses; from pastoral farming to forestry or reversion to native bush.

Areas Susceptible to Soil Slip Erosion in the Pohangina Region



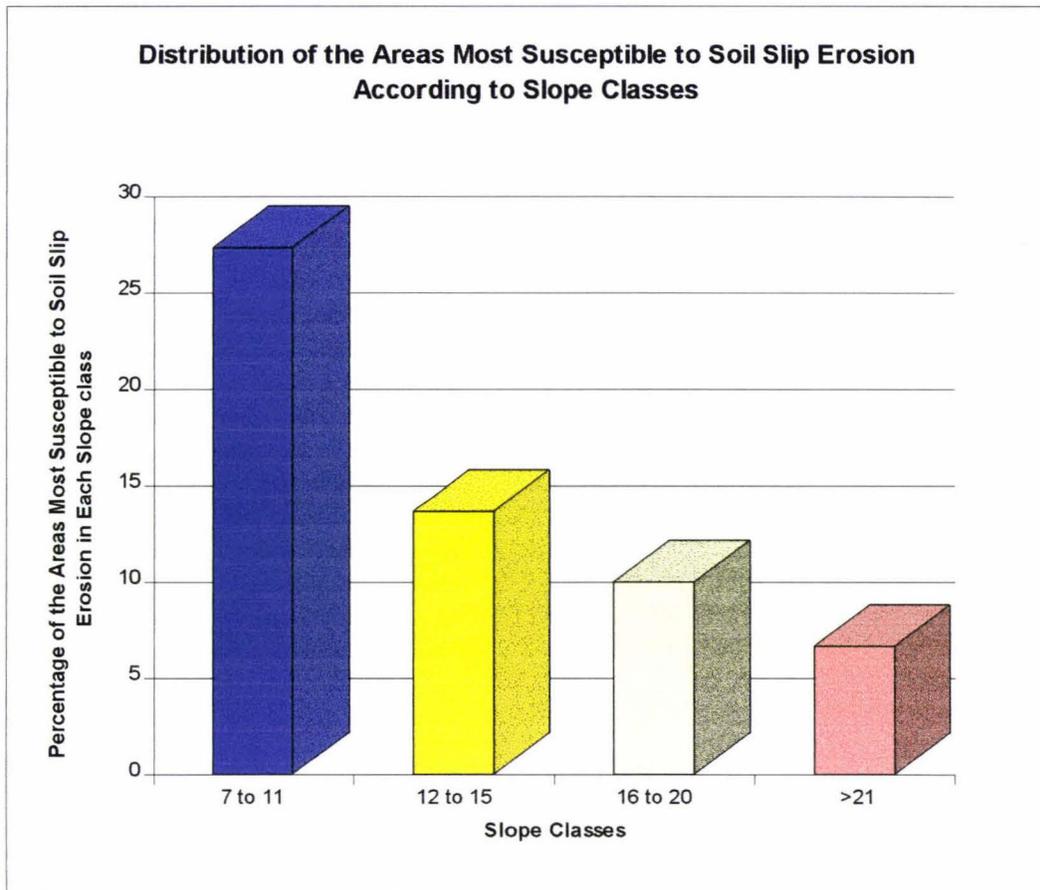


Figure 5.33

Ninety % of the areas most susceptible to soil slip erosion is not covered with deeply rooted vegetation cover.

5.6.3 Summary of Results and Discussion

The following is a summary of the most important results of the analysis of the Pohangina region.

- The Pohangina region covers approximately 23940 hectares.
- 59 % of the area consists of unconsolidated sands which are susceptible to soil slip erosion.
- 23 % of the unconsolidated sands are facing towards N & NE directions and tend to be more susceptible to slip erosion.
- 8 % of the area is covered with deeply rooted vegetation cover.
- 80% of existing deeply rooted vegetation is grown in unconsolidated sands.
- Existing forest and bush is well distributed over all slope classes but steeper slopes have a higher proportion of deeply rooted vegetation cover.
- 90 % of the areas most susceptible to soil slip erosion is not covered with forest and bush.
- 14 % of the Pohangina region is susceptible to soil slip erosion.

The above percentages and information give a general indication of the importance of the soil conservation practices and emphasis that it is time to prioritise changes in land management for some areas.

Of the 3150 hectares in the region susceptible to soil slip erosion only 300 hectares are under deeply rooted vegetation cover, therefore 2850 hectares are at risk from soil slip erosion and it suggested that current land management may cause permanent damage to the land and consequently the farmers would be faced with reduced productivity.

These areas are not contiguous, and any change in land use may impact on surrounding areas that are relatively stable.

CHAPTER VI

Conclusion and Recommendations

7.1 Conclusion

Geographic Information Systems and remotely sensed data can assist in resource management by providing timely, and relatively accurate information without lengthy field survey.

A DEM together with scanned aerial photographs of the study area and a Spot satellite image of the Pohangina Region were used to achieve the objectives of the study. Relationships between topographical features (slope and aspect) and soil slip erosion were investigated in the study area. Results have shown that slopes with NE and N aspects are more susceptible to soil slip than other aspects.

This study has identified possible reasons for the predominance of erosion on N and NE faces slopes. The important factor that influences slip erosion in this area is assumed to be the lack of deeply rooted vegetation, which can protect the soil from slipping.

The techniques described in this study to extract sub-watershed boundaries and mapping of the hillslope aspect units were successfully applied for the study areas to provide a complete subdivision of the watersheds and landscape.

The results were used to identify areas susceptible to soil slip erosion in the Pohangina region. Of 3150 hectares susceptible to soil slip erosion only 300 hectares are under deeply rooted vegetation cover, therefore 2850 hectares are in danger of soil slip erosion and it suggested that

current land management may lead to permanent damage to the land and consequently the farmers would be faced with decreased productivity.

7.2 Recommendations

The most vulnerable landscapes are steep slopes in unconsolidated sands. The most urgent need for these areas is to prevent slip erosion, consequently following recommendations are advised;

Tree planting is the recommended technique for the control of slip and gully erosion. The main mechanisms for the proven action of trees in controlling erosion include the drying out of soil by interception of rainfall and evapotranspiration, and soil reinforcement by roots. Enhanced infiltration of rain water, and the leverage effect of wind on trees, may have negative implications, but they can be considered minor.

- **Dense Tree Planting**

Studies by the Forest Research Institute have shown that large areas of hill country in the Manawatu would be more profitable in forestry than pastoral farming. The *Pinus radiata* forest productivity site index (or its height in meters after 20 years) for the unconsolidated sandstone and moderately consolidated sandstone in the Manawatu-Wanganui region is on average higher than for most other soil parent materials present in the region, ranging from 26-30 meters (Hicks et al, 1993).

The pastures with low production potential and a high susceptibility to erosion are probably more suitable for forest vegetation. *Pinus radiata* is the recommended species. However, restricted grazing may also be utilised during forest establishment.

- Retirement

The Manawatu-wanganui Regional Council encourages the retirement (and reversion to bush) of land which suffering sufficient erosion to indicate that pastoral use is unsustainable. However, land that has suffered moderate levels of erosion may be able to sustain a pastoral system of land use if appropriate soil conservation measures are employed (Manawatu-Wanganui Regional Council, 1995).

- Spaced Tree Planting

Considerable use has been made on farms of wide spaced tree planting, usually with poplars and willows in the form of unrooted 2.5-3.5 m poles. The purpose has been to maintain grazing right to the bole, while ensuring some degree of erosion-prevention. Wide spacing, and the relatively small diameter of a poplar's crown, enable sufficient sunlight to reach pasture on all sides of the tree.

Spaced-planted poplars must be no more than 12 m apart (70 trees/ ha) on unstable parts of a slope if they are to be effective in controlling erosion. Closer spacing may be needed on particularly unstable sites.

Spaced-planting can be seen as a compromise option between the excellent erosion prevention, but minimum grazing, provided by traditional *pinus radiata* forestry regimes, and the sometimes severe erosion that can occur on unplanted pasture. The optimum solution will depend on the situation of the relative economics of grazing and forestry, and on the value that society attaches to environmental protection.

- Agroforestry

Agroforestry is recommended as an ultimate choice. Under a farm forestry system the land may be stabilised, while at the same time, pasture under the trees can be utilised. However, due to high vulnerability to erosion grazing needs to be restricted while the trees become established.

These recommendations are suggested as the most useful techniques that can be used to improve the land management and consequently sustain land productivity while of the same time controlling soil slip erosion.

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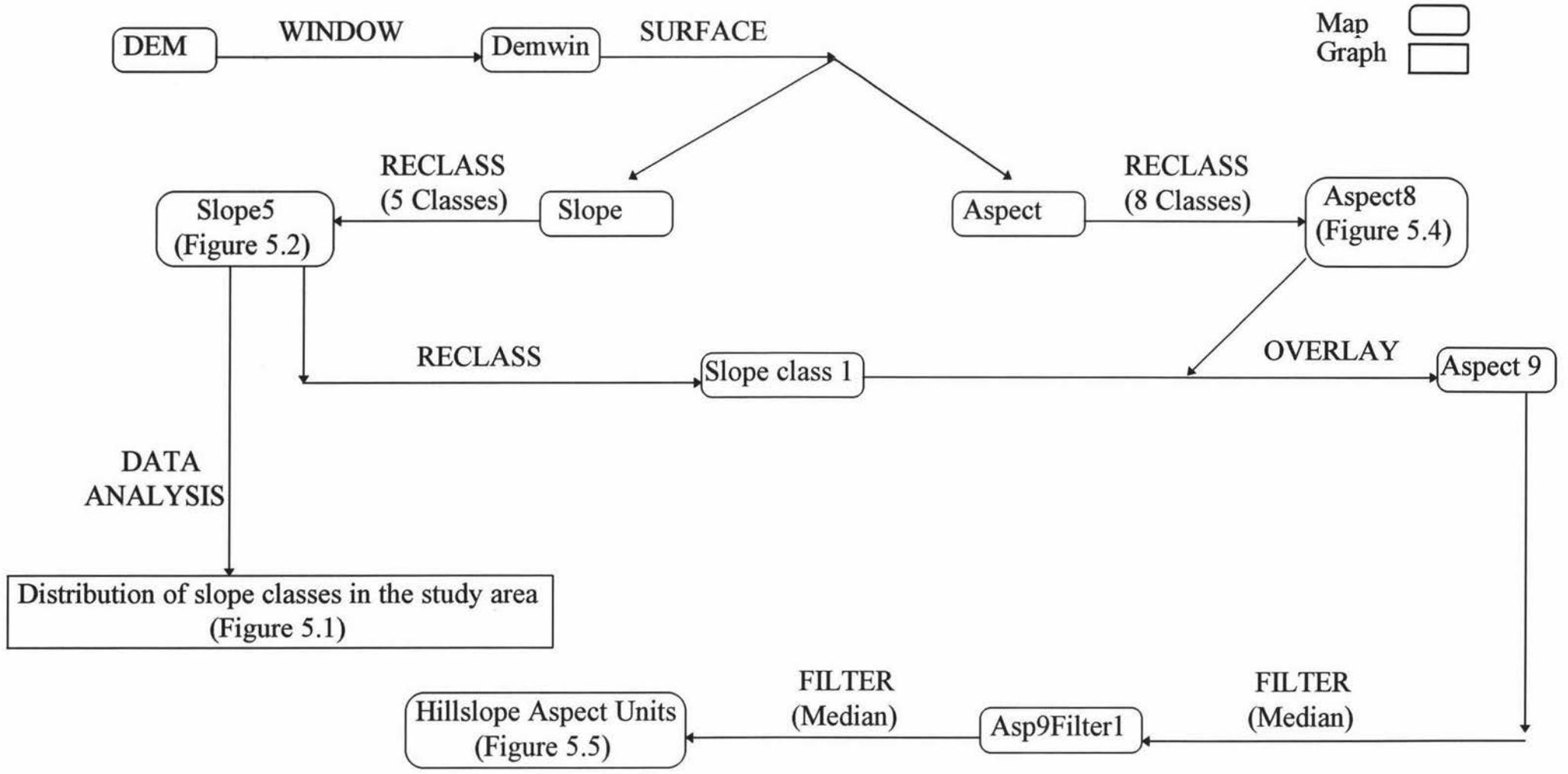
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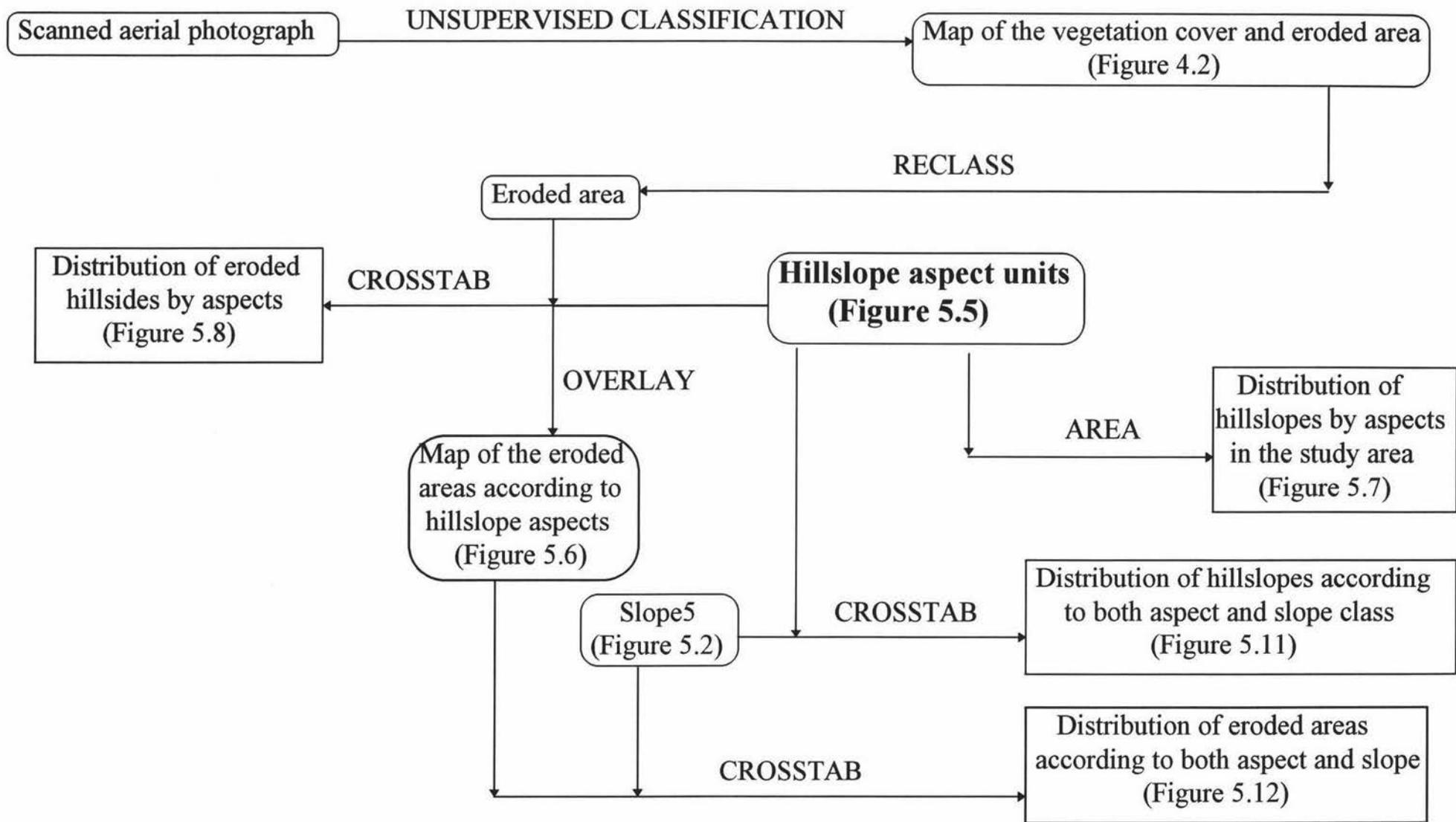
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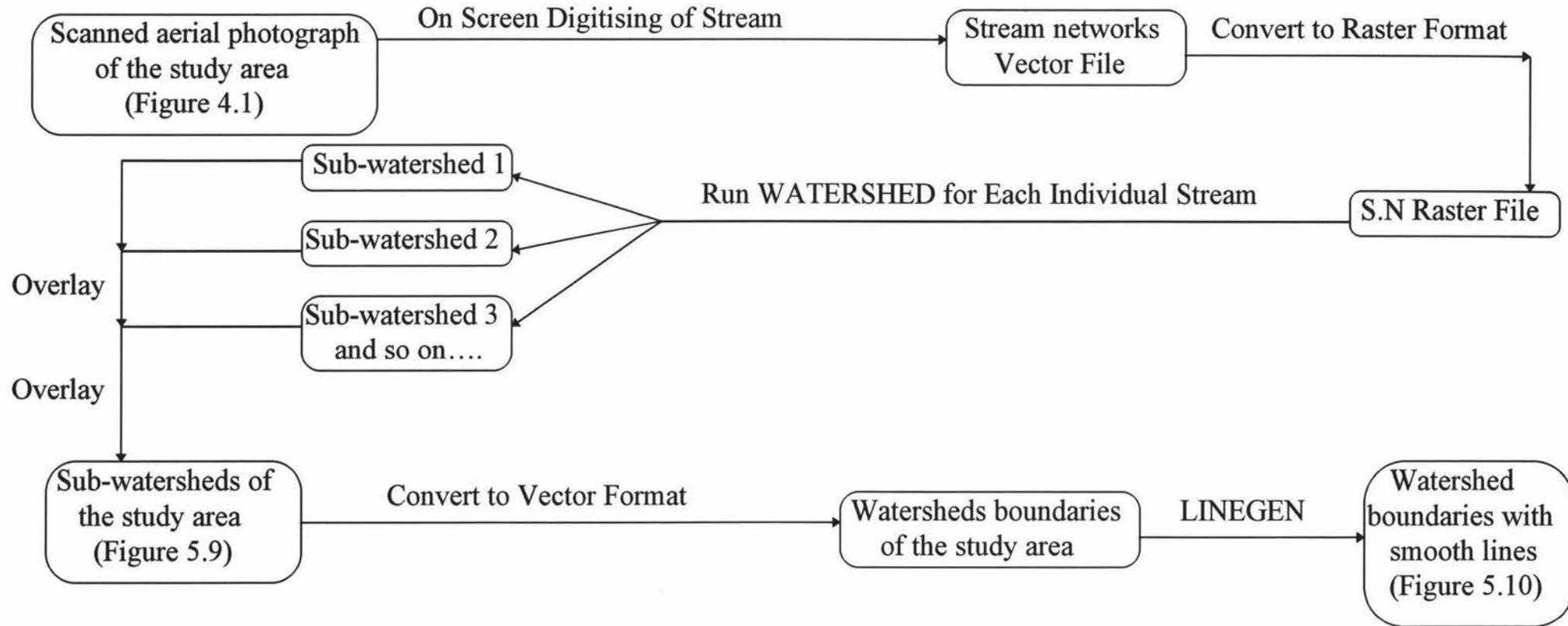
APPENDICES



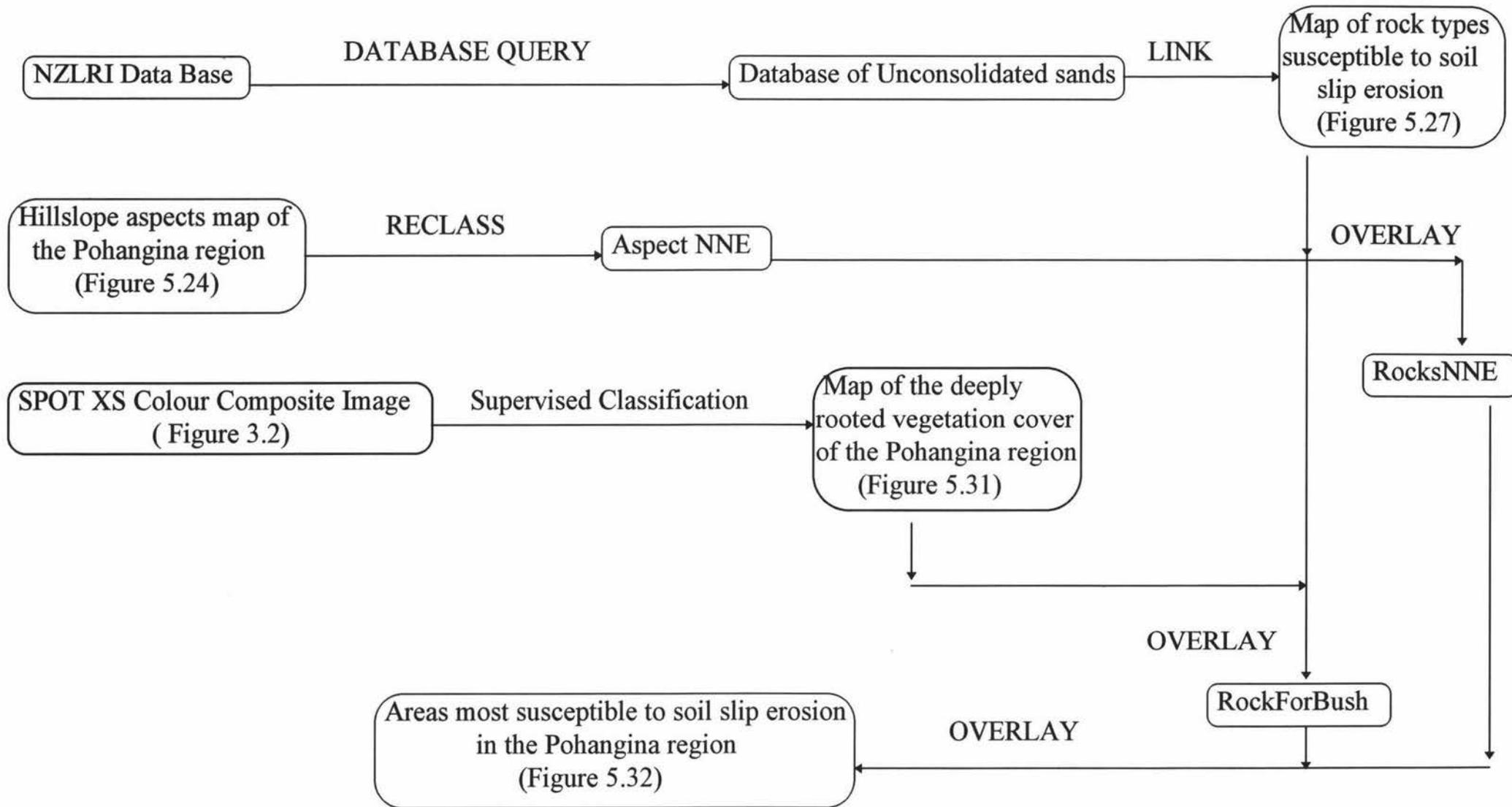
Appendix A: The procedure to delineate hillslope aspect units.



Appendix B: The procedure to determine relationships between soil slip erosion and slope angle and slope aspect.



Appendix C: The procedure to delineate watershed boundaries



Appendix D: The procedure to map the areas most susceptible to soil slip erosion in the Pohangina region.