THE USE OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR FARM SOIL CONSERVATION PLANNING

A Thesis Presented in Partial Fulfilment of the Requirements

for the Degree of Master of Agricultural Science in Soil Science

at Massey University

CYPRIANUS NUGROHO SULISTYO PRIYONO

1993

ABSTRACT

The use of a Geographic Information Systems (PC ARC/INFO) for farm soil conservation planning was demonstrated in several neighbouring properties in the Apiti district, Manawatu. The area (775 ha) was mainly steep and strongly rolling hill country where the dominant land use was pastoral grazing by sheep and cattle. The main objective of this study was to utilize the GIS at each step of the farm soil conservation planning process.

The planning process began with a land resources inventory (LRI) where information on basic physical resources relevant to land management and soil conservation was collected and stored in a database before further processing. Factors collected in the LRI included primary factors (soil type, soil depth, slope, rock type and elevation) and secondary factors (existing erosion, land use, fence lines and ownership, and drainage condition). A digital elevation model (DEM) was developed to display landforms. Field observations were also used and local farmers were given the opportunity to become involved in the planning process.

The next step involved delineating areas of similar land use capability and potential land use. The areas were also assessed in terms of potential erosion and conservation needs. These operations were undertaken by combining the LRI factors in various ways. Results of these assessments were matched to define land units which have similar physical characteristics. Recommendations for management practices were then made by considering combinations of the factors.

The plan was displayed as maps showing the management options available for farmers.

Both map overlay procedures and database analyses were carried out at each step of the planning process. As the map overlay is a unique operation in the GIS, it was used to combine necessary factors from the LRI based on a set of criteria. Database analyses were then carried out using macro commands which were developed according to the criteria. The ability of the GIS for database analyses distinguishes the GIS from other systems whose primary objective is map production. The use of database analyses in this study was a particular example for making recommendations in soil conservation planning. However, the techniques are applicable to many different conditions and different purposes. The maps presented in this study are examples of how it is possible to show the results of analyses. Advantages and constraints of such procedures at each step of the planning process were discussed.

ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to the following people for their contribution towards the completion of this thesis:

Mr. M.P. Tuohy, for his supervision, continual guidance, enthusiasm, encouragement, patience and friendship during the course of my study.

Dr. A.S. Palmer, for his supervision and valuable discussion.

Mr. G.O. Eyles, for his supervision, valuable suggestions, patience and friendship.

Dr. R.B. Stewart and farmers in Apiti for valuable discussion and permission to do field works in their properties.

Messrs. J.R. Fletcher, R.G. Gibb, M.R. Jessen, R. Derose and other officials in Landcare Research Ltd Aokautere New Zealand, for their friendship.

Dr. N.C. Lambrechtsen for his friendship, particularly during my stay in Wellington.

Postgraduate students in the Department of Soil Science, particularly Mr. L.J. Brown, Mrs. S.D. Hendriksen and Ms. Endang Savitri, for their comments, proof-reading and friendship.

The Ministry of External Relations and Trade of New Zealand, for the scholarship grant and the Ministry of Forestry of Indonesia for granting me study leave.

All Indonesian friends at Massey University.

My parents and parents in law for their encouragement and intercessory prayers.

Finally, but the most important, my wife, Anna, and children, Andreas and Putri, for their love, continual support, and understanding during my absences at Massey.

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CHAPTER I

INTRODUCTION AND OVERVIEW

Introduction

The development of Geographic Information Systems (GIS) was started when workers from many disciplines realized that they needed to integrate map data from a variety of sources, before manipulating and analyzing it to provide synthesised output which could be used as part of a decision-making process. This was accomplished following developments in computation, cartography and photogrammetry from 1940 to the 1960s (Smith *et al*, 1987). Since then there has been a rapid increase in the number of GIS as a result of both advances in computer technology and availability of spatially referenced data in digital forms.

Recent developments in GIS have enabled planners to use the system for a wide variety of planning purposes. Planning itself, can be considered as an information processing activity (Scholten and Stillwell, 1990). All relevant map based information can be stored, managed, and presented in a form suitable for use at different stages in the planning process. Soil conservation planning is one of these uses.

At present, a wide variety of GIS have been developed, not only for the natural resource management sectors, but also for applications by public utilities and private companies. Most applications, however, have been on a small scale because they were developed to support policy makers.

This project will discuss the application of GIS to soil conservation planning at a detailed scale. The aim is to demonstrate a GIS that will assist individual farmers to use all available information to develop sustainable land uses. The following overview provides an introduction to the detail in later chapters.

An Overview of Geographic Information Systems

Definitions.

There are difficulties in defining a GIS. Some authors believe that hardware and software are the central foci of GIS. However, others argue that information processing and applications are the key factors. Cowen (1987) considered there are four basic approaches to defining and separating GIS from other types of information systems. They are: process or function, application based, toolboxes and databases. Maguire (1991) identifies eleven different definitions from several sources. Despite these differences, all definitions have a single common feature, namely that GIS are systems which deal with geographical information.

A definition given by Environmental System Research Institute/ESRI (1990) is considered to be appropriate "a GIS is a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modelling and display spatially referenced data for solving complex planning and management operations". Scholten and Stillwell (1990) listed three main tasks of a GIS. Firstly, there is the storage, management and integration of large amounts of spatial referenced data where the spatial data bases contain two types of information, locational and attribute data. The second task is to carry out analyses related to the geographical component of the data. The third task involves the organization and management of large quantities of data in such a way it can be easily accessible to all users. The definition also indicates that a GIS has some functions which are similar to other systems such as CAD (Computers Aided Design). The main characteristic of a GIS which distinguishes it from other systems is its ability to analyze spatial data. Burrough (1986) emphasises that GISs are the result of linking parallel developments in many separate spatial data processing disciplines. Hence, the relationship between GIS and other systems such as CAD, computer cartography, database management and remote sensing information is very important in order to clarify the definition of GIS. The best view, however, was given by Maguire (1991) who stated that GIS are a subset and not a superset of other types of information system.

The definition gives the impression that a GIS is computer based. Some authors consider GIS can be either manually or computer based (Fletcher and Gibb, 1990; Star and Estes, 1990). A manual GIS usually comprises several data elements such as maps, overlay transparencies, aerial and ground photographs, statistical reports and survey reports. These sets of data are compiled and analyzed with such instruments as stereoscopes, transferscopes and mechanical and electronic planimeters (Star and Estes, 1990). Processing sequences, which are usually done on computer based GIS, can be carried out on manual GIS without reducing accuracy. However, difficulties increase when a manual GIS is used for complicated analyses on large data sets. Thus, the selection of an appropriate GIS should consider type of analyses, data access requirements, areas of interest and duration of the project. Based on this assessment, this study will use the computer based GIS.

Data Structure

A spatially referenced database can contain two types of data, namely locational and attribute data. Locational or spatial data has two or three dimensional co-ordinates of points (nodes), lines (segments) or areas (polygons). Attribute data, on the other hand, refers to the features or attributes of points, lines or areas. Moreover, there are three forms of data structure in which locational data can be incorporated within a GIS, namely : raster, vector and quadtree. A raster data structure consists of a regular grid of cells that are termed pixels. Each grid cell has a unique number representing the type of a particular attribute. The position of each grid cell is referenced by a row and a column. Satellite imagery and some other remote sensing data are instances of information which is contained in a raster structure. In vector data, points, lines and areas are incorporated as cartesian co-ordinates in the computer, which enables the data structure to produce more precise representation of reality. The relationship between locational data and attribute data, which is usually called topology, is very important within vector data structure. Each element is related to a record in the database with the same unique identification number. Burrough (1986, 1987) described in detail the comparison, choice and recommendations in use between raster and vector data structures. In general, a raster data structure allows spatial analysis more easily in comparison to a vector data structure, but results in unimpressive maps. A vector data structure, on the other hand, is able to provide a database and elegant graphics but spatial analysis is more difficult. A quadtree data structure falls between raster and vector data structures as data is stored in grid cells of variable size.

A vector data structure was chosen for this study because it has the ability to produce more precise boundaries and the outputs are more easily understood by individual farmers because lines rather than pixels are plotted. For these reasons, PC ARC/INFO, a vector GIS, was chosen for this project.

Components of a GIS

According to Burrough (1986), GIS have three main components: computer hardware, sets of computer software and an organizational context. The last component was separated by Maguire (1991) into two elements: data and liveware. Each of these components needs to be in balance in order for the system to function satisfactorily.

1. Computer hardware

In general, computer hardware which is used in a GIS has six components. The main component is the central processing unit (CPU) which is linked to five other components: disk drive, tape drive, digitizer, visual display unit (VDU) and display device. The disk drive provides space for storing data and programs, whereas a tape drive is used not only for backing up data but also for communicating with other systems. A digitizer is a device which converts line data from maps or plans into digital form and sends the data to the computer. A VDU, more commonly known as a terminal, allows users to display maps quickly, whereas a display device is a printer or a plotter which produces hard copies of the files. This project used the 486SX personal computers (PC), a GTCO digitizer, HP plotter, HP paintjet colour printer and Brother 8HL laser printer.

2. Computer software.

GIS software consists of the following basic technical modules: data input, data storage and database management, data output and presentation and data transformation.

- Data input modules undertake activities transforming data captured from maps, field observations and sensors into digital form.
- Data storage and database management deal with the way to organize the position of the data and their linkages with attribute

data which is known as topology (Robinove, 1986).

- Data output and presentation concerns displaying and reporting the result of analyses to the users.
- Data transformation includes two types of transformations, one which is used to remove errors and the other is to achieve particular requests.

This project used PC ARC/INFO Version 3.4D and PC TIN Version 2.2D.

3. Organisational components.

This component concerns the organizational context of where a GIS is placed, so that it can be used effectively. A GIS needs accurate data to produce information for management purposes. Furthermore, the feedback from management is also expected to improve the GIS. Each of these aspects should be properly integrated into the whole work process. For these reasons, GIS require not only an investment in hardware and software but also in training of personnel and managers to use the technology.

Each of these components of a GIS was used in the farm soil conservation planning project.

An Overview of Soil Conservation Planning.

The first recorded example of modern soil conservation was in 1877 when a German soil scientist, E Woolny, investigated soil erosion using small plots (Sanders, 1990). In 1907 the United States Department of Agriculture (USDA) declared an official policy of land protection to control soil erosion. Nowadays, soil conservation is practised throughout the world. The basic principles of effective soil conservation have been used in many civilisations. However, in some places these principles have been incorrectly applied resulting in severe soil degradation. Frequently, this misuse has been because soil conservation techniques have been transferred to different areas without a complete understanding of the physical and social conditions at these sites. Basic soil conservation principles are transferable but correct applications of these are highly dependent on local conditions such as climate, land and soil characteristics, farming practices and social and cultural attitudes. To be effective, soil conservation practices need to be based on planning developed according to local conditions. For this reason, it is essential that accurate information about local conditions is collected and properly interpreted in order to provide appropriate information for planning soil conservation measures.

Information and Planning Levels.

The type of information to be used in the planning process should be paralleled by the level of assessment and planning (Perrens and Trustrum, 1984). Three levels can be identified: policy, program and practices levels.

- The policy level needs general information at a regional or national scale because this level is usually intended to identify national needs and potentials.
- The program level concerns translating the purposes and objectives that have been decided on into policy. The translation includes identifying and describing resources and problems. Technical assessment at this level is more detailed than at the policy level and the assessment usually includes qualitative assessment of land capability, erosion hazard and its impacts on management activities.
- The most detailed level is the practices level. Planning at this level should be based on very detailed quantitative assessments in order to design management actions.

Based on this structure, planning in this study was at the program level.

Soil Degradation and Soil Conservation.

In general, the term soil conservation can be interpreted as "the promotion of the optimum use of land in accordance with its capabilities in such a way so that its use will assure its maintenance and improvement" (Dudal, 1981). Perrens and Trustrum (1984, 1985) identified that soil conservation means "a variety of activities by humans to control the rate of degradation, loss of soil and yield of sediment from the landscape by wind, water and gravity". Hence, soil conservation will always be related to soil degradation. Lal and Stewart (1992) discussed in detail processes of soil degradation and factors responsible for soil degradation. They also identified three processes in soil degradation, namely physical, chemical and biological processes. This study, however, will place most emphasis on physical processes. Soil degradation is a physical process caused mainly by incorrect land use and poor management. The soil degradation is also caused by uses of land which are not compatible with the land's capability. These usually result from ignorance, economic and social attitudes (Sanders, 1990).

In summary, there are four factors important for soil conservation planning: accurate information about the land resources, soil degradation and soil conservation, land capability, appropriate land use and land management. In planning these factors should be integrated to develop management actions which can minimize the risk of soil degradation. In other words, undertaking this integration in a soil conservation planning process will enable planners to provide important information of land management for the development of sustainable agriculture.

Soil Conservation Planning.

The sequence of information collection and analysis for farm soil conservation planning is shown in Figure 1.

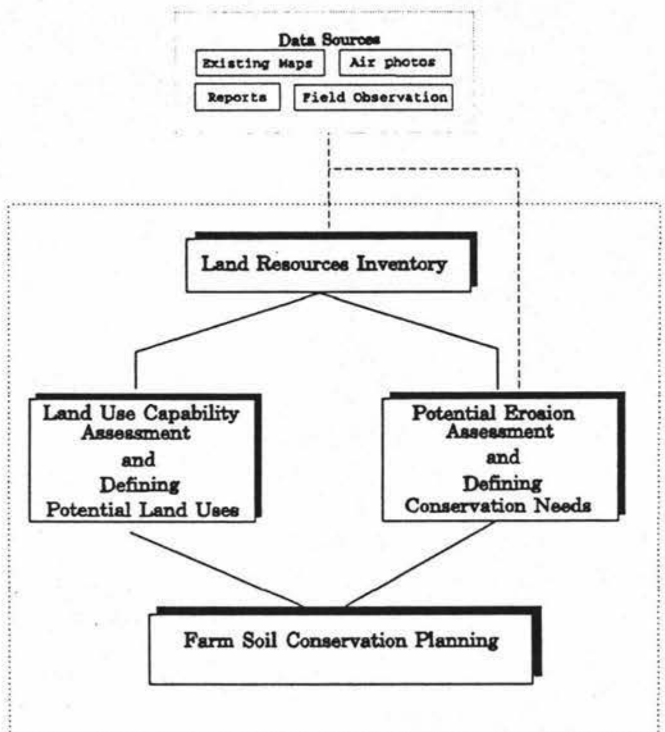


Figure 1: The sequence of steps for soil conservation planning

Land resources inventory mapping involves collecting information about physical characteristics of the land. In this study, information on basic physical resources relevant to land management and soil conservation was collected and stored in a database for further processing. The information can be recorded in various ways, such as direct measurement, sampling, reference to existing databases, photo interpretation and remote sensing techniques involving digital image processing. The study used information from previous studies, e.g Rijkse (1977), Cowie (1978); photo interpretation and fieldwork. The land resources inventory will be discussed in more detail in Chapter III.

Land Capability assessment classifies the land according to its capability for sustained production taking into account the physical properties of the land recorded in the inventory. The result is a map in which the land is put into land use capability classes ranging from the highest (class I) to the lowest (class VIII). The capability class gives information about the total degree of limitations. The degree of limitations may be assessed from steepness of slope, erosion history, susceptibility to flooding, liability to wetness or drought, depth of soil, climate, soil properties and nutrient supply. The first four classes comprise land suitable for cultivation for cropping, with the limitations to use increasing from class I to class IV. Class V to class VII comprise land unsuitable for cropping use but suitable for pastoral or forestry uses. The limitations reach a maximum with class VIII, which is suitable only for protection purposes. The major kind of limitations is indicated by the LUC sub classes (Soil Conservation and Rivers Control Council/SCRCC, 1971). The land capability assessment enables parts of a farm to be classed as suitable for different land uses. Hence, the assessment can be used to define potential land uses. More discussion about land capability assessment and its application for land use planning will be given in Chapter IV.

Potential erosion is assessed using information collected in the land resources inventory for each unit area. The potential erosion is determined by combining the information on land use, slope, rock type, soil type and climate information. Based on the potential erosion, the conservation needs were then defined for the study area.

Finally, soil conservation planning can be developed by matching information on soil conservation needs and potential land uses. Recommendations for particular soil and land management practices can be developed for each 'land unit,' from a consideration of all of these factors. Detailed discussion will be given in Chapter V and VI respectively.

Objective

The objective of this study is to utilize a GIS (i.e PC ARC/INFO v3.4D) at each step of the soil conservation planning process described in Figure 1 and to comment on the strengths and weaknesses of such a procedure.

To achieve this objective, the study focused on utilizing the GIS at each step of the process:

1. To identify major features, as well as existing and potential problems.
2. To record, manipulate, analyze spatial data of the study area as required in the planning process.
3. Using the digital elevation model (i.e PC TIN) to show landform phenomena which affect land and soil characteristics.

4. To analyze the database in order to determine the land use capability class and subclass.
5. To select areas that are suitable for a variety of purposes and to define potential land uses.
6. To identify areas with information about potential problems enabling soil conservation measures to be identified and to recommend specific management activities.
7. To display results of analyses in easily interpreted map form.

CHAPTER II

SITE DESCRIPTION

General Description.

The Study area comprises 775 hectares of terraces, hills and river flats; approximately 2 km north-east of Apiti and 65 km north east of Palmerston North City. It is bounded on three sides by the Oroua Valley Road, Pohangina Valley East Road and Table Flat Road (Figure. 2).

A number of streams either flow through or rise in the study area and discharge into the Oroua river approximately 2 km to the east. The area is dominantly hill country, however in the northwest high flat terraces provide a major change in relief. Elevation rises from 440 m to 660 m asl.

Seven properties occur in the study area with the main land uses being intensive sheep farming and fattening of cattle.

Climate.

The nearest rainfall recorder stations are at Table Flat and Apiti which are approximately 1 and 2 km respectively from the study area, while the closest wind observation station is Ohakea Airfield, approximately 50 km to the south west. The average annual rainfall ranges from 1 300 mm at Apiti to 1 830 mm at Table

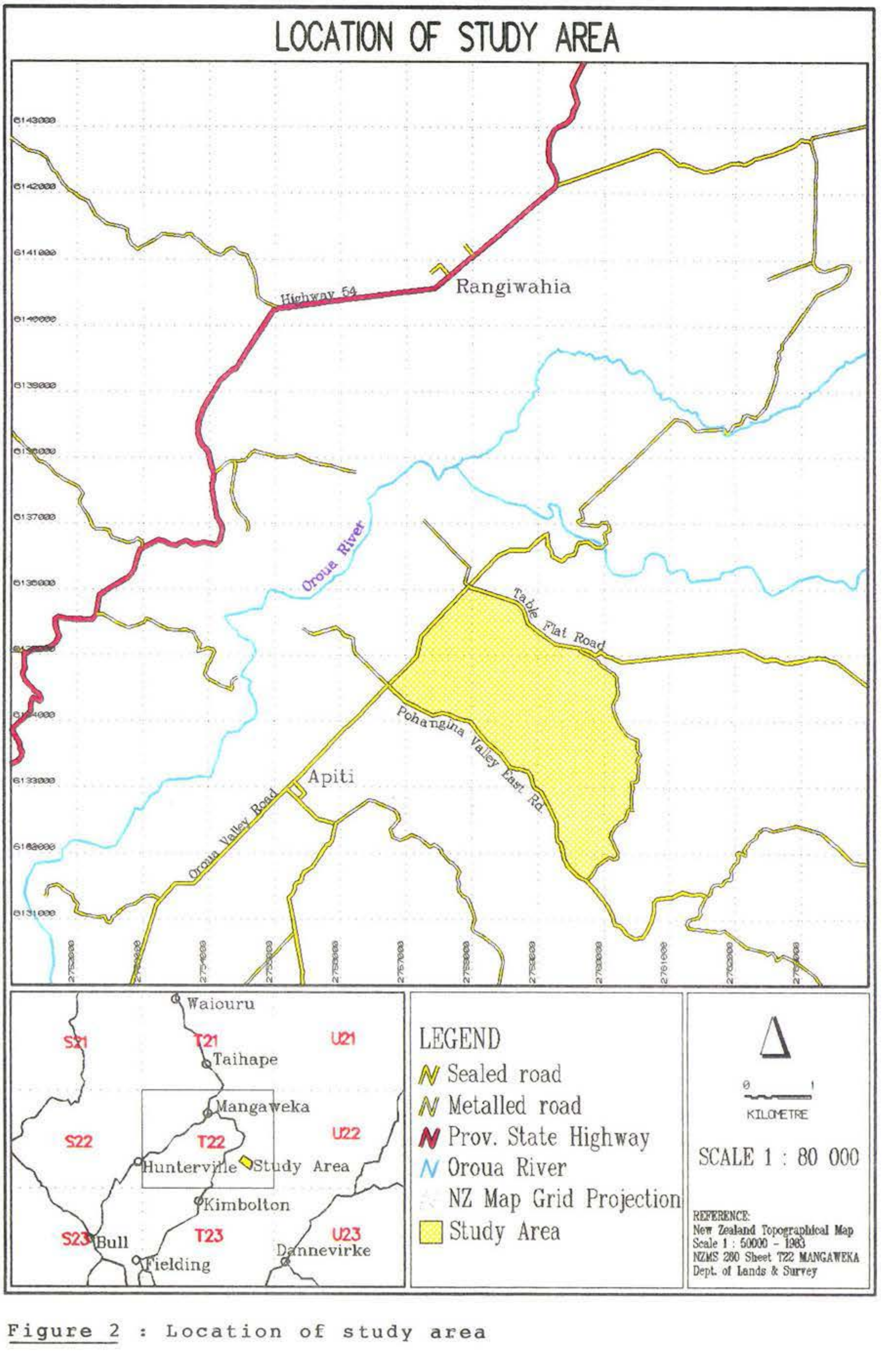


Figure 2 : Location of study area

Flat (Rijkse, 1977) and occurs predominantly with the prevailing westerly and north-westerly winds. It is further influenced by the orographic effects of the Ruahine Range. Monthly rainfall distribution from Table Flat and Apiti stations is shown in Figure 3. This indicates the seasonal variation is relatively slight with June the wettest month and March the driest. Wind observations at Ohakea Airfield suggests that north-west to north winds are predominant and gales are frequent.

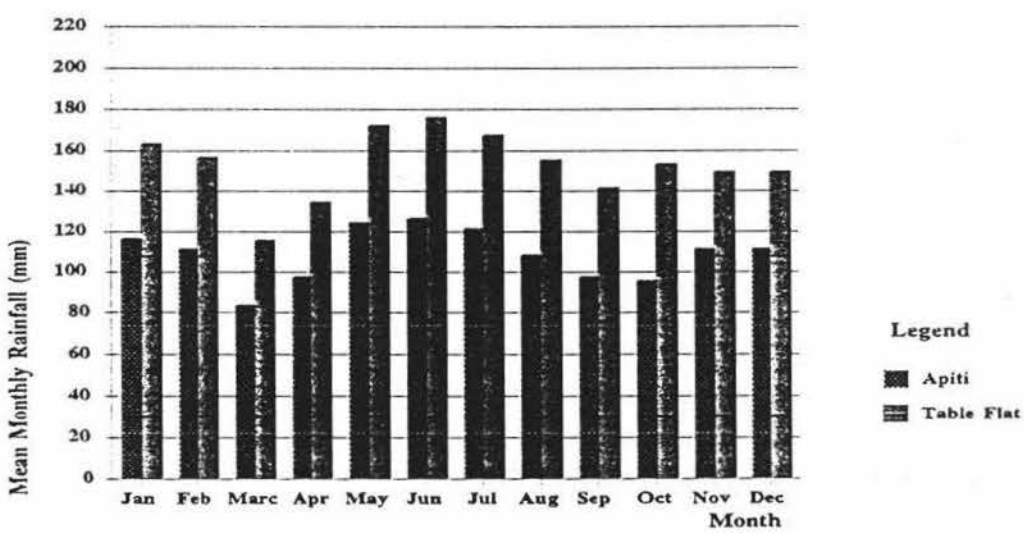


Figure 3 : Mean monthly rainfall data of the study area (1921 - 1950)

Physiography.

Three major physiographic units are recognized in the study area, the river flats and younger fans, the high terrace and the hill country :

- The river flats occur along the streams in the northern part of the study area and several places on the western and southern margins. They are characterized by imperfectly drained soils.
- The high terrace is located to the north-west of the study area where the elevation rises from 440 m asl in the west to about 500 m asl in the north. These areas are characterized by gently undulating surfaces.
- The hill country is the dominant land unit. It is dominated by a large landslide which is predicted to have occurred within the last 15 000 years (pers comn A.S Palmer, 1992). It starts at the southern margin of Table Flat and extends down to near Pohangina Valley East Road. The resulting topography is very complex, influencing the soil formation and distribution of rocks. For instance, small patches of soil types which are the same as those on the high terrace are found in the lower hill country. Elevation ranges from 440 m asl in the south to about 670 asl adjacent to the Table Flat.

Soils.

Information about soils within the study area can be obtained from New Zealand Soil Bureau (1954), Rijkse (1977), Cowie (1978) and Cambell (1979). These surveys mapped soils at reconnaissance scales, from 1 : 250 000 to 1 : 50 000. In this study soils are mapped at a semi detailed to detailed scale of 1 : 20 000.

Rijkse (1977) identified and described 6 soil types in the study area, namely: Dannevirke silt loam (D), Dannevirke silt loam rolling phase (DR), Kiwitea fine sandy loam rolling phase (KwR), Whetukura silt loam (Wt), Whetukura hill soils (WtH) and Utuwai silt loam (Ut). This study delineates more closely the boundaries of these soil types through detailed field work. The method and results of this soil mapping will be discussed in the next chapter.

The characteristics of each soil type as described by Rijkse (1977) are as follows:

Dannevirke silt loam (D)

Dannevirke silt loam soil is characterized by a dark brown friable silt loam with a strongly developed nut structure in the top 15 to 20 cm overlying about 15 cm of yellowish brown friable silt loam with a weakly developed blocky structure. The soil was formed from loess and is classified as an integrade between yellow brown loam (YBL) and yellow brown earth (YBE) soils. Soil analyses indicated that this soil is likely to respond to phosphorus and potassium. The soil occurs mainly on the high terrace to the north-west with some small patches also occurring in the hill country due to the historical landslide landform.

Dannevirke silt loam, rolling phase (DR).

This soil is similar to Dannevirke silt loam. It was also formed from loess with interbedded sandstone underneath the loess and a deep, friable, dark brown and dark yellowish brown silt loam top soil. The sub soil has a weakly developed yellowish brown silt loam texture which becomes firm with depth. It occurs mainly on rolling slopes on high terraces adjacent to Table Flat and on rolling hill slopes in the north.

Whetukura silt loam (Wt).

This soil is a yellow brown earth (YBE) formed on fine sandstone and loess. It has a brown to dark brown, friable, top soil with a strongly to moderately developed nut structure. Subsoil is yellowish brown and has a weakly developed to moderately developed, block structure.

Whetukura hill soils (WtH).

In contrast with the Whetukura silt loam soil which is found on loess, this soil was formed on interbedded sandstone. The difference between the two can be identified in the field by the loess content. It is moderately acid, has a high organic matter content and is moderately leached. Under natural conditions the soil has low to medium levels of potassium and phosphorus (Rijkse, 1977).

Kiwitea fine sandy loam, rolling phase (KwR).

The soil is formed on a mixture loess and interbedded sands. The top soil comprises about 20 cm of brown friable sandy loam with a strongly developed nut structure overlying about 15 cm of dark yellowish brown friable sandy loam with a moderately developed nut structure. The sub soil is a yellowish brown sandy loam with a weak to very weakly developed nut structure. Compared to Dannevirke silt loam, the soil is more leached and weathered. The soil is classified as a yellow brown earth (YBE).

Utuwai silt loam (Ut).

Utuwai silt loam is a Recent soil which normally occurs in the valleys. In the study area it is found in the northern and eastern parts. This soil was formed from colluvial materials from the adjacent hill slopes. It is slightly acid and weakly leached due to its poor drainage and immaturity. The soil is characterized by a brown silt loam top soil overlying a yellowish brown mottled fine sandy loam. The top soil has a moderately developed nut structure and the subsoil a weakly developed blocky structure.

Land Use and Vegetation.

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

According to the local farmers, maize for greenfed has been grown on the flats but this was stopped eight years ago because of soil compaction problems.

Small forest blocks of *Pinus radiata* are scattered through out the study area. Most have been planted to stabilize slip or slump erosion. Remnant native trees such as Red Beach (*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 which have drainage problems.

Farm dams are scattered throughout the study area to provide stock water. Most are located in 1st or 2nd order streams with catchment areas between 2 to 5 ha.

CHAPTER III

LAND RESOURCES INVENTORY

Introduction

The first stage in the soil conservation planning process was to undertake a land resource inventory (LRI). This was an inventory of physical resources relevant to land management and soil conservation. Information was collected from various sources, such as air photo-interpretation and field observation, existing maps and reports. Information collected emphasized physical condition because land degradation is difficult to reverse. It did not record nutrient status because it was considered these deficiencies could be corrected without too much difficulty.

Factors collected in the LRI can be grouped into primary and secondary factors. Primary factors were permanent attributes such as elevation, slope, rock type, soil type and soil depth. Secondary factors were those which could easily be changed, such as drainage status, existing erosion, soil conservation practices, and fence and ownership data. The procedure used to collect these factors is illustrated in the flowchart in Figure 4. The following section discusses in more detail the LRI mapping process.

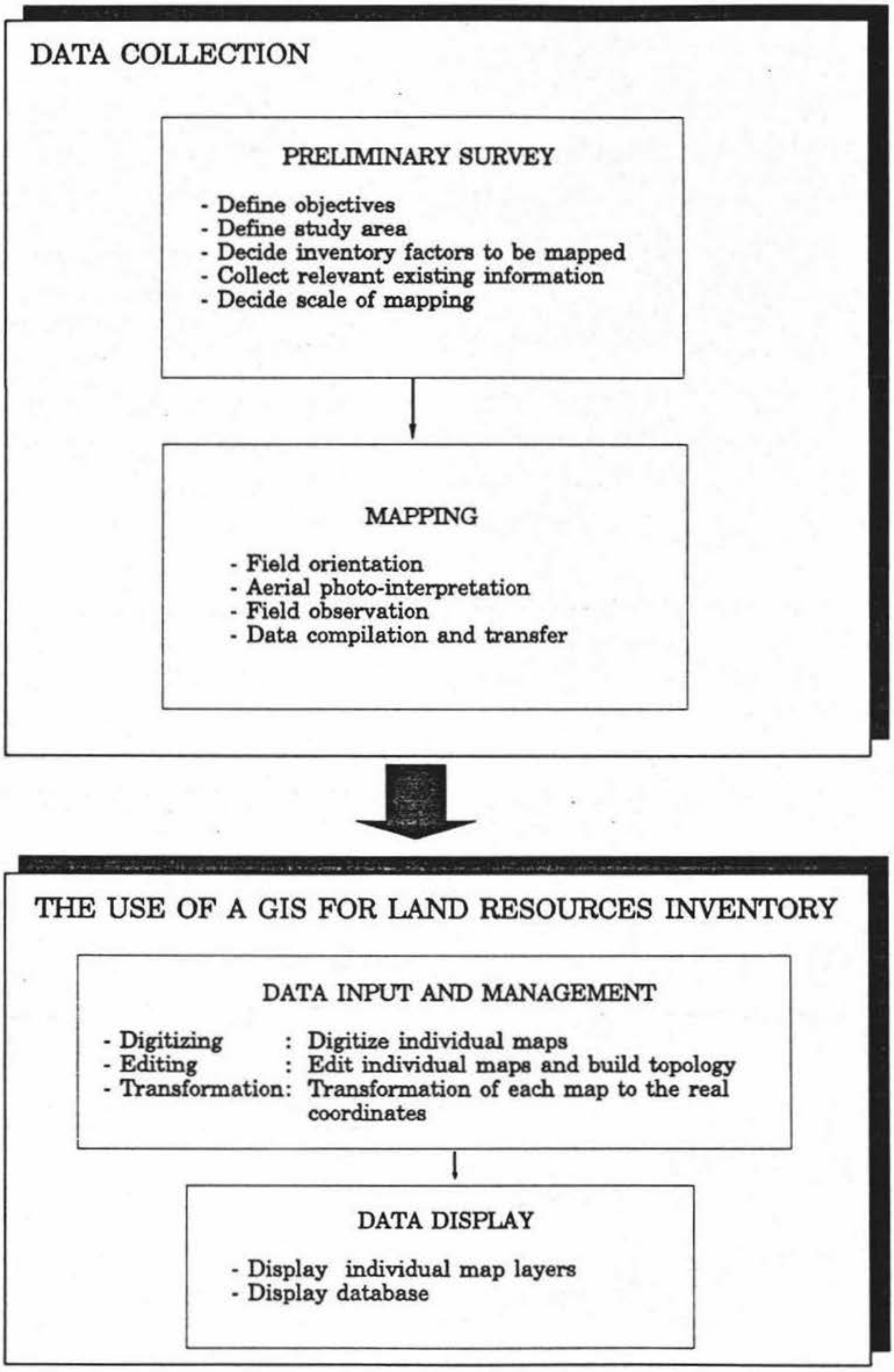


Figure 4 : Procedure for land resources inventory

Data Collection

Preliminary Survey

The preliminary survey in this study included all those activities undertaken prior to field mapping. Activities involved are listed in Figure 4. These activities were designed to provide starting points for further work on the planning process.

The objective of the LRI was to collect the physical data necessary for farm soil conservation planning. Thus, the data should be related to the planning and it should be able to provide information for soil and land management practices. The location and general characteristics of the study area were described in Chapter II. Inventory factors collected in the mapping activities include primary factors (soil type, soil depth, rock type, slope, elevation, drainage density) and secondary factors (existing erosion, existing land use, drainage status, ownership). Most of the data were collected from field observation, air photo-interpretation and a combination of these two.

Collecting existing information resulted in an inventory of data or results of previous studies related to the study area. Data collected in the preliminary survey were mainly climatic (i.e. rainfall and temperature data). Two previous studies had been undertaken in the general study area. One included the study area (Rijkse, 1973 and 1977) and the other was nearby (Milne and Campbell, 1969). Information about soil and rock types was obtained from these.

Resource maps that were used for this study were:

1. Rock type and soil type maps:
   - Soil Map of Pohangina County, scale 1 : 63 360, 1977, Rijkse (1977).
   - New Zealand Land Resources Inventory Worksheet, Sheet No N139/Mangaweka, scale 1 : 63 360, 1979, National water and Soil Conservation Organisation.
   - Geological Map of New Zealand, Sheet No 11, scale 1 : 250 000, 1964, Department of Scientific and Industrial Research.
2. Base maps and air photographs:
   - Panchromatic black and white aerial photographs, survey number 8316 F/13-15 and G/13-14, February 1984, scale 1 : 25 200, New Zealand Aerial Mapping Limited.
   - New Zealand Topographical Map, Sheet NZMS 260/T22/Mangaweka, Scale 1 : 50 000, 1983, contour interval 20 m, Department of Lands and Survey.
   - New Zealand Topographical Map, Sheet NZMS 270/T22D, 1981, Scale 1 : 25 000, contour interval 20 m, Department of Lands and Survey.

Before the field mapping was undertaken it was necessary to decide the scale because this determined the degree of detail required, the minimum area to be identified and the intensity of observations. It was considered the intensity of observation also should be more detailed than the publication scale to increase the accuracy. The publication scale chosen was 1 : 20 000 and the intensity of observations was at 1 : 15 000. This scale was chosen as it was considered that the scale of 1 : 20 000 was appropriate for a farm plan.

Mapping

Field Orientation

Field orientation was undertaken to become conversant with the study area and its features so that key interpretations could be developed to support air photo-interpretation processes. This occasion was also used to introduce the surveyor to landholders and get permission for working on their properties.

As the plan will be used by landholders, they should be involved in the planning process. Therefore, during field orientation, land holders were involved in discussions on the objectives of the study and how it matched with their needs. The history of their land management programs was also discussed.

Aerial photo-interpretation

Aerial photo-interpretation was carried out to identify major features on the air photographs. The various stages of photo-interpretation include: recognition and identification, analysis, classification and deduction (Caroll *et al*, 1977). These cannot always be easily separated as they are usually used in combination.

1. Recognition and identification is 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 field work. Obvious objects such as buildings, streams, roads and tracks could be identified in advance. There might be, however, many clues to identify an unknown feature. None of the clues had certain meaning, but if all or most of the clues indicated the same conclusion, that conclusion was probably correct. The interpretation key that had been created during the field orientation was used in this stage.

2. Analysis is where the features and patterns directly visible on air photographs were identified. Adjoining forms or surfaces were compared to establish their individuality. This comparison was made systematically over the study area. Specific features that were analyzed were slope, drainage status, land use and existing erosion.

3. Classification occurs where the various individual features resulting from the analysis are classified. The classification for these features was done using Table 1. The delineations resulting from this stage were not final

<u>Table 1</u> : The Classification of factors which were collected in the LRI

Factors	1	2	3	4	5	6	7
Slope *	Class A 0 - 3 dgs	Class B 4 - 7 dgs	Class C 8 - 15 dgs	Class D 16 - 20 dgs	Class E 21 - 25 dgs	Class F 26 - 35 dgs	Class G > 35 dgs
Drainage status *	Very poorly drained	Poorly drained	Imperfectly drained	Moderately drained	Well drained	Excessively drained	
Soil depth *	Very shallow 0 - 15 cm	Shallow 16 - 45 cm	Mod. deep 46 - 90 cm	Deep 91 - 120 cm	Very deep > 120 cm		
Existing erosion **	None	Slight erosion	Moderate erosion	Severe erosion	Very severe erosion		
Rock type **	Loess and tephra	Interbedded sand-siltstones	Alluvium/ colluvium	Interbedded lime-sanstones			
Soil type +	Dannevirke silt loam	Dannevirke silt loam roll.phase	Whetukura silt loam	Whetukura hill soils	Kiwitea fn sandy loam roll.phase	Utuwai silt loam	
Land use and vegetation **	Pasture	Scattered woodlots (*Pinus radiata*)	Native trees	Native shrubs	Mixed conservation trees and native trees		

* Based on Land Use Capability Handbook (1971)

** Identified during field observation.

\+ Field observation and deduction from Rijkse (1977) because they would be checked during the field observation.

4. Deduction comprises a combination of observations from the photos with knowledge from other sources in order to obtain information that can not be gained from the photo alone. Sometimes, this is considered as a separate stage of photo-interpretation, however, in this study it was an inherent part of every stage of photo-interpretation. Hence, deduction was carried out throughout the photo-interpretation processes to achieve a more accurate interpretation.

The principles of aerial photo-interpretation followed the conventional principles which have been described in various references related to photogrammetry, remote sensing and mapping such as Carroll *et al* (1977), Dent and Young (1981), Mc Rae and Burnham (1981) and Lillesand and Kiefer (1987). The photo-interpretation of black & white air photographs is based on tonal properties (tone, pattern, texture, shadow, shape and size) of the air photographs and relief. Identifying features and delineating their boundaries can be done using the tonal properties in combination with the relief in three dimensional view. Stereoscopic analysis of an air photograph pair enables an interpreter to observe relief differences and thus delineate features more precisely. In the air photo-interpretation process, the following terms are significant:

1. Tone is the shade of grey; ranging from black to white for panchromatic photography. Tonal changes are often related to changes of phenomena

such as soil conditions when bare soil is exposed either directly or indirectly through the vegetation cover. Sometimes tonal properties can reflect the depositional and erosional history, hydrological regime or vegetative cover.

2. The pattern of features is their spatial arrangement in a repeated sequence or characteristic order.

3. Texture is the pattern of tone contrast at a scale that is too small for individual elements to be distinguished.

4. Shape refers to individual features not repeated as a pattern. The shape and size of features can often be useful guides to their identification.

5. Shadow refers to individual features that reflect little light and are seen dimly or not at all. Shadow is the main factor in determining the shape and size of an object and, with illumination, defines relief.

Using these principles, the air photo-interpretation using a mirror stereoscope, determined slope angle, rock type, soil type, soil depth, drainage status, existing erosion, land use and fence lines. A transparent sheet was overlaid on the air photographs enabling interpreted data to be drawn on the sheet instead of directly on the air photographs. Each factor was drawn in a separate layer.

1. Slope angle.

Possibly the easiest air photo-interpretation is slope angle since this is clearly seen in a stereoscopic examination. Landscape units with similar slope angle were delineated. Using tonal properties, slope steepness could be identified by the darkness of the toned shadows. These were calibrated in the field using an abney level or clinometer.

2. Soil type.

Delineation of slope classes for each landscape unit was important as slope changes are usually accompanied by changes in soil properties. The sharper the break of slope the more definitive the demarcation of one soil type from another (Carroll *et al*,1977). Soil type was indicated using slope angle, the landscape units, and information from the soil type descriptions in Rijkse (1977).

3. Rock type.

Rock type data is also important because many intrinsic soil properties are inherited either directly or indirectly from the parent rock, particularly as slope increases. Air photo-interpretation for rock type identification was undertaken using information from landscape units. Flat areas in the study area, for instance, could be identified as containing loess or alluvium/colluvium, whereas steep hill country might be sandstone or limestone. This identification would be defined later during field observation. In addition, rock type terms in this study did not conform to standard geological terms because the purpose of the identification was to group rock types on the basis of physical characteristics which are relevant to soil conservation.

4. Soil depth.

Soil depth was delineated according to the position of land on landscape units. On hill country, landscape units can be subdivided into: summit area, shoulder and backslope, footslope and toeslope (Hole and Campbell, 1985). Generally, the deepest soils are on footslopes and toeslopes because these are deposition areas whereas shoulders and backslopes have shallower soils than both the footslopes, toeslopes and the summit areas. After delineating these areas of similarity, the actual depth of the soil was measured in the field by auguring.

5. Internal drainage.

To assess the internal drainage status, indicators based on tonal properties were used. Wet soils were generally darker toned than similar dry soils because of their greater light absorbtion. Rushes (*Juncus spp*) in irregular dark toned patterns indicated imperfectly drained areas. The topographic position, strips of one or more types of vegetation, tone changes within the same land use (e.g pasture), ponds or dams in concave areas were some additional indicators that were used as keys to indicate the drainage status of the study area.

6. Existing erosion.

The existing erosion was delineated using indicators based on the tonal properties and position of features in the landscape unit. Bright tone features with coarse texture on sloping areas could be identified as erosion scars. The severity of existing erosion was estimated on the basis of the percentage of area eroded in a landscape unit. The erosion type was confirmed during field observations.

7. Land use.

Identification of land use patterns from air photo-interpretation was simple because they were dominated by pasture with only scattered groups of trees. The groups 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. The specific type of vegetation was defined later during the field observations.

8. Fence lines and ownership

The difference in tonal properties enabled many individual paddocks to be delineated for the fence and ownership maps. The property boundary was confirmed only after consulting with individual local farmers.

Field Observations

Air photo-interpretation was an aid to, not a substitute for, conventional field studies. Although it was possible to delineate many features from air photo-interpretation, they could not be fully described or fully classified without field observation. Hence field observation was required not only to collect information which was not easily available from the photo-interpretation but also to confirm the photo-interpretations.

There are two approaches to selecting observation sites in field surveys : grid survey and free survey (Dent and Young, 1981 and Milne *et al* 1991).

- In grid survey, observations are regularly spaced to produce a rectangular grid over the study area. This approach is suitable for complex areas (e.g areas having complex soil pattern) with limited support from air photo-interpretation. However, the grid survey approach has too many disadvantages for a detailed survey such as inflexibility of site selection.
- In free survey, observation sites are selected using the surveyor's judgement, keeping in mind the objectives of the survey, supported by air photographs and ground evidence. Site observation can be located where they are the most useful and the most representative. Observation density is adjusted according to the requirements of the survey and the complexity of the area.

This study used the free survey approach to select observation sites, consequently the field observations were supported by air photo-interpretation and specific features on the ground. Observation sites for profile description and site assessment are shown in Figure 5. At each observation site a series of measurements were taken measuring: slope angle, soil profile and site description.

In this study, air photo-interpretation was used to delineate provisional slope unit areas. These were then checked in the field by measuring the slopes at observation sites. In addition to these, measurements were made at three further sites for each slope map unit. Sites chosen related to the assessed range of slope. The average slope was used to confirm the slope class (Table 1).

Soil type, rock type, soil depth and drainage status data were confirmed during description of the soil profile at each observation site in the study area. The soil profile description was made according to Taylor and Pohlen (1962). Factors which were assessed include:

1. Horizon identification and depth
2. Mottling
3. Texture
4. Structure
5. Colour
6. Consistence.
7. Rock outcrops

All information collected in the field profile descriptions were matched with the profile descriptions from Rijkse (1977) to identify soil type and rock type for each unit delineated in the air photo-interpretation. Drainage status data that was derived from air photo-interpretation was confirmed by identifying mottles, their

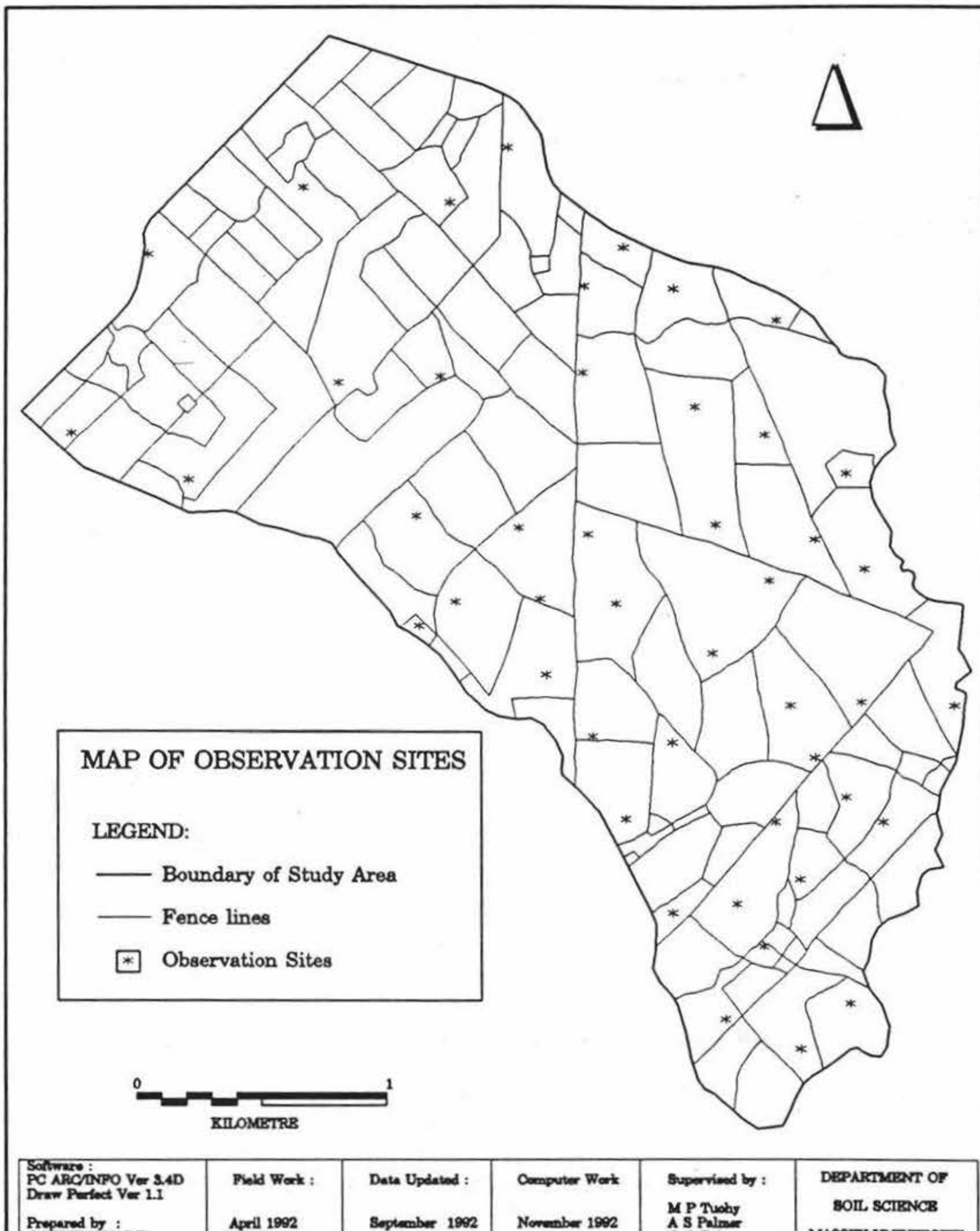


Figure 5 : Observation Sites of the Study Area

distribution and intensity in the soil profile descriptions.

Site assessments were also carried out in adjacent observation sites to confirm land use, fence lines and existing erosion provisionally delineated in the air photo-interpretation. These maps were also adjusted by observing areas around observation sites and around map units of the individual maps. Newly planted woodlots, changes of fence lines and new erosion scars were features that were included in the adjustments of land use, fence and existing erosion maps respectively.

Data Compilation and Transfer.

In this part of the study all data collected during the field observation stage was compiled and the data were prepared for encoding to the GIS. Thus, all field notes that were taken during field observation had to be quantified and managed so that they could be directly typed into the database whereas individual map layers needed to be transferred to the base map for digitizing.

As the study area is dominantly hill country, there will be scale distortion effects. These geometric anomalies were eliminated by transferring the data from air photographs to base maps using the zoom transferscope. The zoom transferscope is a device that allows the operator to simultaneously view both a map and a pair of stereo photographs. A pair of air photographs were placed below a lens system which project an enlarged or diminished image onto a glass screen. When a base map was placed on the screen, the image of the air photographs was superimposed on the map. This enabled features on the air photographs to be transferred to the base map. A darkened room was required for this instrument and a base map had to be prepared for each data layer. The base map was the NZMS 270/T22D topographical map scale 1 : 25 000, enlarged to 1 : 15 000, on which the study area boundary had been delineated.

The zoom transferscope was also used to define reference points which could be identified both in the air photographs and on the map. The coordinates of these reference points were used as tic points in the digitizing processes. The minimum number of tic points needed for the process was four, however, it was more accurate to identify additional points spread through the study area. In this study ten reference points were identified.

The Use of the GIS for Land Resources Inventory

As shown in Figure 4. the utilization of the GIS for LRI is in two parts; data input and management, and data display. Data input and management comprised preparing data for either further analysis or for data display, whereas data display involved operations to display the data or individual map layers.

Data Input and Management

Data input and management operations in this project are shown in Figure 6. The following describes the components of this figure.

Digitizing.

Data input is the operation of entering data to the GIS. There are two types of data to be entered, positional (geographical) data and associated attributes that express what the feature represents (Burrough, 1986). In this study, entering the data to the GIS was done using a digitizer for mapped data and direct typing for attribute data. A digitizer is an electronic device for entering the spatial coordinates of mapped features to the computer. Thus digitizing can be seen as the process of converting the spatial features on a map into a digital format.

In digitizing, points, lines and polygon features that form a map are converted into x,y coordinates. A point is represented by a single coordinate, whereas a line is represented by a string of coordinates. Therefore if lines are combined with a label point inside the outline, this will identify the area or polygon. It clearly shows that points are used for two different purposes: to represent point features and to identify the presence of a polygon. In other words, digitizing is a procedure for capturing a series of points and lines.

Digitizing converts data compiled in map form from air photo-interpretation and field observation to a digital form in the computer. In PC ARC/INFO,

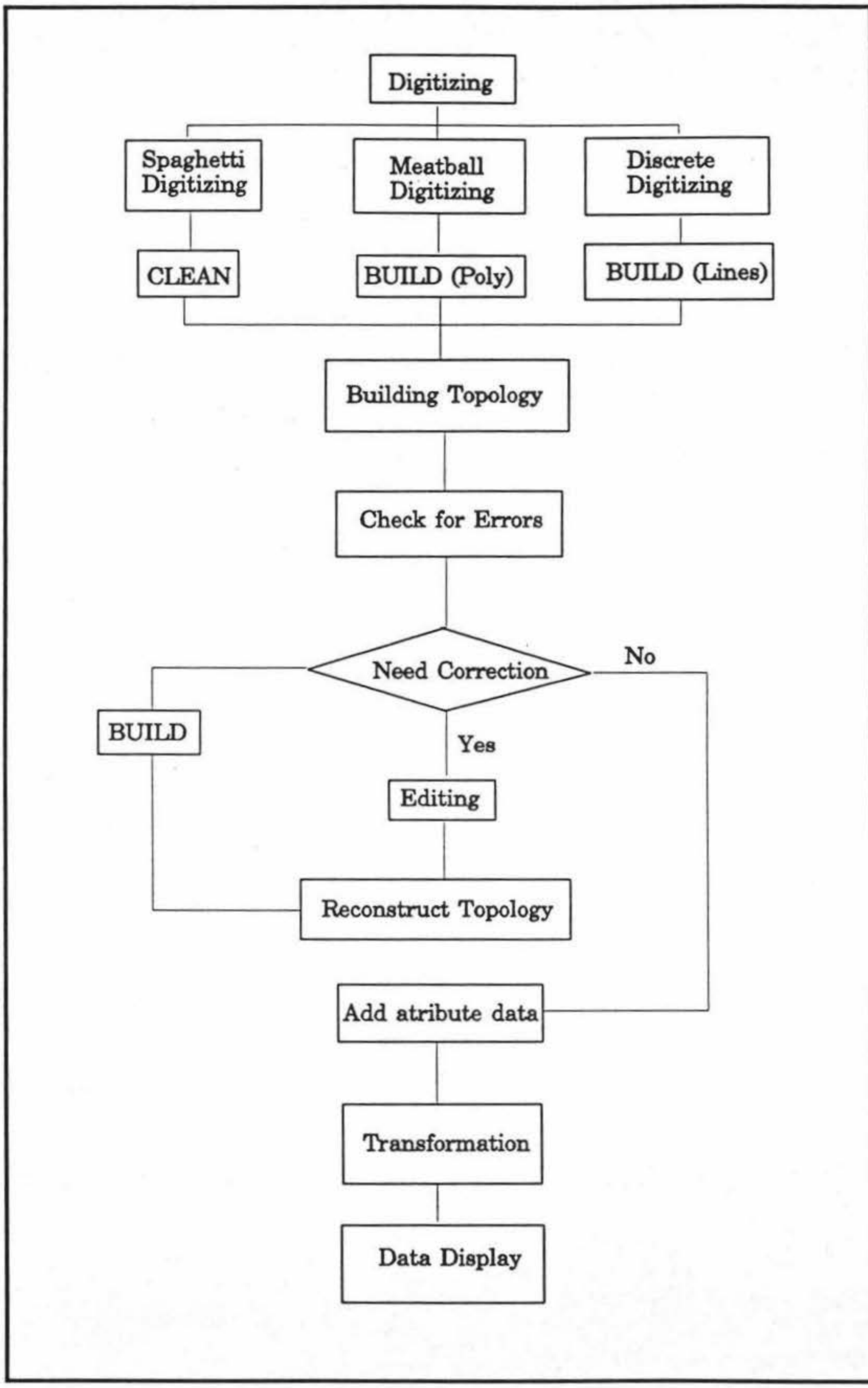


Figure 6 : Data input and Management operations
(modified from ESRI 1990)

digitizing is done using PC ARC/INFO's sub systems (i.e ADS/The ARC Digitizing System or ARCEDIT). The first stage of digitizing was creating a tic coverage using ADS. Tics are registration points representing the location of known points on the earth's surface for which coordinates are known. ADS was used to create a new coverage from the tic coverage. Thus ADS began with a dialogue to identify the tic location and the extent of the coverage. Reference points that had been defined in transferring map data were used for tics.

To check the location of tics, the plot of tics at the same scale as an original map sheet was produced. This plot was then laid over the original map sheet to verify wether the location of the tics was accurate. The accurate location of tics was critical as it determined the accuracy of the following digitizing process.

Burrough (1986) suggested that digitizing should not be undertaken for more than 4 continuous hours because digitizing fatigue would affect accuracy. Chrisman (1987) noted that an average digitizing time of about 8 hours was needed for a coverage of 300 complicated polygons and an average editing time of 4 hours for the coverage. Hence, digitizing a map might not be completed in one session.

A new digitizing session or creating a new coverage requires establishing coordinates for that coverage. This can be done by digitizing at least four tics of that coverage and their corresponding location. After all these tics were entered, a RMS (Root Mean Square) error was calculated in the digitizer unit and displayed in the dialogue. The RMS is the calculated difference between the recorded and the specified tic location. The RMS errors should be kept as low as possible because they determine the accuracy of point coordinates which will be entered.

ESRI (1990) sets the limit of RMS value at 0.003 or 0.004 when digitizing in inches[1] depending on the nature of the data, the scale of maps and the material from which the data is digitized. Generally more precise data will have lower acceptable RMS values.

As indicated previously, digitizing a map can be undertaken in two ways: digitizing points and digitizing lines. Digitizing label points in a polygon coverage is usually called "meatball" digitizing. A polygon is labelled by entering a point somewhere inside it. In PC ARC/INFO, however, digitizing label points in polygon coverage can be done automatically. Digitizing points to represent point features, on the other hand, should be undertaken separately to the polygon coverage to avoid confusion. This digitizing cannot be done automatically.

When digitizing lines, "spaghetti" digitizing ignores the intersection between lines so that lines can be digitized as one long arc. It results in the set of arcs overlapping, much like spaghetti. Discrete digitizing, on the other hand, creates a series of connected arcs by digitizing each intersection as a node. Explicitly marking each intersection will provide greater coordinate accuracy.

In this project, digitizing lines used a combination of spaghetti and discrete digitizing. The latter was applied in the inside of the study area, whereas the former was applied particularly in the edge of the study area.

1. The GTCO digitizer works in inches.

Building Topology and Editing

When data is entered into the computer, the spatial relationship between the data should be developed and digitizing errors should be identified. Errors may occur during digitizing because even when the digitizing had been done carefully, some lines might not connect properly (i.e undershoots and overshoots). Such errors in maps needed to be defined for correction. Therefore, identifying errors could only be done after topology had been constructed.

Topology is the relationship between geographic features (Burrough, 1986; ESRI,1990; Star and Estes, 1990). Each of these features is assigned an internal number. These numbers are then used to determine arc connectivity and polygon contiguity. The values are recorded in a feature attribute table, created during the construction of the topology. As geographic features can be expressed as points, lines and polygons, building topology is also undertaken for points, lines and polygons. A point attribute table (PAT), an arc attribute table (AAT) and a polygon attribute table (PAT) are created for point, line and polygon coverages respectively. Thus, each geographic feature in the coverage has a corresponding record in the feature attribute table. Some additional data may be needed to describe the detail of each feature. Adding some data about features to a coverage involves associating new information about the feature with existing records in the attribute tables and it can be done if both tables have a common item. Most data layers in this project were developed as polygon coverage except the drainage density (streams) and fence line maps which were digitised as line coverages and locations of dams and observation sites maps which were became in point coverages.

In ARC/INFO, map topology is constructed using BUILD and CLEAN commands. Although both are used to construct topology and create attribute tables, they are not always the same. BUILD assumes that the coordinate data has already been corrected and it can not create intersections (discrete digitizing). Thus, BUILD can be used to construct topology for points, lines and polygons. CLEAN, on the other hand, is able to create intersections and places nodes wherever lines intersect. Hence, CLEAN processes only lines and polygons.

The process of constructing topology helped to identify errors that might occur in the digitizing process, because when topology was constructed, arc intersections were created, the arcs that make up each polygon were identified and a label point was associated with each polygon. Some common errors, that could be identified after constructing topology, could be listed as follows:

1. Arcs that did not connect to other arcs.
2. Polygons that were not closed.
3. Polygons that had no label point or too many label points.
4. Incorrect ID.

In operation, these errors could be identified and displayed using appropriate commands such as : NODEERRORS or LABELERRORS.

Once errors had been identified, they needed to be corrected. The main purpose of editing is to correct errors so that any analysis and subsequent maps would be valid. Fixing errors was one of the most important steps in constructing the coverages. Fixing errors means adding some missing data and replacing incorrect data with the correct data, thus there may be many ways of fixing errors.

Editing errors of a coverage would alter the coverage topology. Hence, topology of the coverage must be reconstructed to re-establish the spatial relationship. Reconstructing topology could be done using the same commands used to create it: BUILD or CLEAN. The CLEAN uses a specified dangle distance[1] and fuzzy tolerance[2] which can adjust some intersection coordinates, consequently the same dangle distance and fuzzy tolerance must be specified if a coverage is re-cleaned. Alternatively, editing was carried out on the original coverage so that it could be re-cleaned by specifying a new coverage for CLEAN each time it was edited.

Transformations

When the map had been digitized, its coordinates were held initially as digitizer measurements. To make the information meaningful and also to impose a scale factor, it was necessary to convert these measurements to the real coordinate system in the same projection as the source map. This process is called a transformation. Thus, transformation is a process of transforming data to a

1. **Dangle distance is the length of dangling arcs. A dangling arc occurs when an arc is digitized past an intersection (overshoot).**

2 **Fuzzy tolerance is a minimum distance between coordinates in the input coverage.**

particular map projection.

A map projection is a mathematical conversion which is used to create a flat map sheet from a spherical surface (ESRI, 1990). Common map projections are UTM (Universal Transverse Mercator) and The Polar Stereographic Coordinate System. A map projection is used to ensure a known relationship between locations on a map and their true locations on the earth. It is most important, however, to use the same map projection for all maps being analyzed. The map projection used in this study was the New Zealand Metric Grid. This system expresses x-y coordinates in seven digits.

Transformation to the New Zealand Metric Grid began by creating an empty coverage which contained only tics. This was accomplished using the ARC command CREATE to copy the tics. In TABLES, tic coordinates were then changed to real coordinates. Finally, the transformation was completed by transforming the tics of each coverage from digitizer units to real-world coordinates using the ARC command TRANSFORM.

There are two transformation functions in the TRANSFORM command: projective and affine transformations. The projective transformation is used only to transform coordinates digitized directly from aerial photographs. At least four tics are needed for this transformation. On the other hand, affine transformation scales, rotates and translates all coordinates in the coverage using the same equation. This transformation is based on a minimum of three tics.

All coverages used in this study were digitized from single factor maps which were compiled from photo-interpretation and ground truthing. Consequently, the affine transformation was used in every transformation. Since transformation is only the process of converting coverages from digitizer units into real-world units, the transformation does not perform "rubber sheeting" as this stretches and compresses the original map. Therefore, the RMS error is used to calculate errors for each transformation. A high RMS error indicates that the input and output coverage tics do not match properly. Although RMS errors may not be zero they should be kept as low as possible. For transformations, ESRI (1990) sets an RMS error value of less than 0.005 if the digitizer unit is in inches. If the RMS error is too high, the reference points should be digitized again, and the transformation repeated.

Digital Elevation Model.

As the purpose of the GIS was to manage data for further analyses, a Digital Elevation Model (DEM) was constructed to better utilize the elevation data. Some authors argue about the terms DTM (Digital Terrain Model) and DEM. Burrough (1986) prefers to use DEM because the term "terrain" often implies attributes of a landscape other than altitude of the land surface. In contrast, Weibel and Heller (1991) used DTM as it allowed the use of landscape attributes other than topography. In a more general sense, DTM may be used as a digital model for any single-valued surface. However, this study prefers to use the term DEM because the data was derived from utilizing elevation data for display phenomena related to topography.

A DEM is a major constituent of a GIS because it enables elevation data to be used for modelling, analyses and display phenomena related to topography or similar surfaces. According to Weibel and Heller (1991), most elevation data are derived from three alternative sources: ground surveys, photogrammetric data capture and from digitized cartographic data sources.

- Ground survey techniques are generally very accurate but relatively time consuming and are therefore generally only suitable for small areas or for specific projects.
- Photogrammetric data capture is based on the stereoscopic interpretation of aerial photographs or satellite imagery and this is more suitable for nation wide data collection.
- Cartographic data includes contour maps. There are useful for medium or small areas and have been used in this study.

The DEM can be constructed using two data structures: a rectangular (elevation matrix) grid and TIN (Triangulated Irregular Network) (Star and Estes, 1990; Weibel and Heller, 1991). This study used the TIN data structure to construct the DEM (i.e PC TIN). TIN is a set of connected triangles generated from points with x,y,z values. It represents a three dimensional surface by connecting points that have x,y,z values with non overlapping triangles. Each triangle represents a flat facet of surface (ESRI, 1990)

Constructing the TIN was begun by building TIN topology using point or line data. Similarly in PC ARC/INFO, PC TIN topology also refers to the relationship among features, in this case, among the nodes and triangles. In operation, TIN topology is built by the BUILDTIN command. In contrast with building topology in PC ARC/INFO, the CLEAN command should not be used on a three dimensional coverage because CLEAN can add nodes and create extra arcs. A three dimensional coverage can be created by generating TIN and writing it to a coverage using PC TIN's command VIEW3D. However, it may be useful to select appropriate azimuth, altitude and z factors of the three-dimensional coverage to get the best view. For this purpose, the VIEW command was used to define what azimuth, altitude and z factor which would be used for VIEW3D.

In general, there are three different surface representations which can be used for a three dimensional coverage: diagonal lines, fishnet lines and TIN triangles. The kind of surface representations have to be decided in executing VIEW3D as well as the resolution of the lines. This resolution sets the number of diagonal of fishnet lines. Using PC TIN, diagonal lines surface has more advantages than others because this surface representation does not result in either broken net lines as in fishnet lines or complicated surfaces as in TIN triangles. Hence, diagonal lines were used in this study to display three dimensional coverages.

The scale of the contour map used was 1 : 25 000 with 20 m contours. Some point data were added to compliment the line data. This was needed, particularly in the summit areas, to eliminate flat surfaces. TIN was then created using line and point data that was derived from the contour map.

Once TIN has been built, the coverage can be developed for several purposes such as engineering (e.g cut and fill volumes and profile), draping, contouring or interpolating elevation data, delineating watersheds and ridge lines and creating slope or aspect maps. Draping was mainly used in this study to display phenomena related to geomorphology. The soil type map, slope and rock type maps were draped onto a three-dimension coverage to enable processes related to soil development to be illustrated. Unfortunately, draping polygon coverages onto TIN did not work properly, but draping line or point coverages did. Thus draping of the soil, rock type and slope maps were done using draping lines. Consequently, the output coverage needed to be rebuilt into polygons.

Since TIN was created from a contour map with an interval contour of 20 m, it could not produce detailed slope or aspects maps because the TIN had very coarse triangles. Because of this, the slope map was derived from air photo-interpretation and ground truthing. However, PC TIN produced an accurate elevation map with the elevation interval decided in the look up table. Delineating catchment areas and ridge lines to select suitable sites for dams also did not give satisfactory results.

In summary, despite displaying phenomena related to geomorphology, the TIN in this study, derived from contour maps, did not provide useful data for planning.

Data Display

Data display in the LRI represented either individual LRI data or interpretive data which was derived from a combination of several LRI factors. Data representation should be understandable to users and compatible to other systems. The most common understandable data display are maps, graphs and tables. To be compatible to other systems, the data display must be in the form of a magnetic tape. The LRI data display was mainly done in individual maps and by showing their databases.

The display of LRI data in the form of maps can be as single factor maps or multi-factor maps based on attributes which correspond to the feature in the maps (Fletcher and Gibb, 1990). For multi-factor maps, display of the database may be necessary to show all information in an integrated formula.

Display of Individual Maps.

Maps were used to represent LRI data because they were very effective ways to illustrate information about objects and their spatial relationships. Consequently, attributes were stored in the form of individual map sheets.

There are three main functions of maps: recording information, communicating information and processing information (Weibel and Buttenfield, 1988). A composition is essential before any map is processed because poorly designed maps can be difficult to interpret, and may convey false ideas about the facts contained in the display. A good map composition should involve four basic factors: the geographical area, the level of information, scale and format. The correlation of these factors was discussed by Keates (1989).

According to Monkhouse and Wilkinson (1971) there are two groups of maps which involve displaying quantity as well as spatial distribution: isopleth and choropleth maps. In isopleth maps, quantities are indicated by lines of equal value. Contour maps and rainfall maps are the most common examples of an isopleth map. Choropleth maps, on the other hand, depict average values per unit area. In GIS, choropleth maps are commonly used for data display. In vector-based GIS, choropleth maps are polygon coverages. Variation in tones, colours or patterns, which is usually called shading, is used to indicate the data values within polygons. Shading should be chosen with care in order to clearly display information.

Most individual attributes in the LRI were displayed in choropleth maps. Map compositions were done in ARCPLOT using a sequence of macro commands. These macro commands (i.e simple macro commands/SML) were then stored in SML files in order to minimize space in the computer and to simplify reproduction of the maps. Some thematic maps were also created to display line and point coverages.

It is important to note that a better quality of map display will increase the effectiveness of information for decision making. For this reason, a basic knowledge of map design should be understood by GIS users.

Display Database.

Display database of LRI factors were mainly for maps which need to be supported by their attribute tables in order to show some other associated attributes that cannot be represented in the map. These are usually multi-factor maps or maps which have excessive associated information (e.g. soil profile descriptions on some observation sites).

Display database is also useful in the following steps to show the database of some interpretative maps which enable the relationship of each attribute table to be indicated. The display can be done by plotting the attribute table to particular plot files. The plot files can then be edited, using compatible programs, for better performance. Hard copies of the database can be produced by printing the plot file.

Results and Discussion

Results of LRI mapping.

Individual LRI factor maps which were created in this study are:

1. Soil type
2. Land use

3. Fence and ownership

4. Slope

5. Drainage status

6. Soil depth

7. Elevation

8. Existing erosion

9. Rock type

These individual map layers are shown in Appendix 1 and are displayed at scale of 1 : 30 000 due to the paper size limitation. Reasons for selecting the inventory factors are discussed below.

The soil factor was collected because of its influence on land and land management practices. The importance of soil factors was recognized by Gibbs (1966) who called soils "the flesh and blood of land". Soils cannot be omitted from assessment of land as a resource for human requirements. The soils needed to be classified before they could be used for interpretation. The first step in this classification was to define the units to be mapped. The unit of classification was the soil type and the criteria for its establishment were similarity of profile characteristics and environments of formation. An assessment of soil properties and their responses to management can be used for a variety purposes such as defining irrigated areas (Burrough, 1987), selecting particular crops and land use planning (Schreier, 1983) and assessment of erosion risk (Sentis, 1980 and Burrough, 1986). However, land has wider concepts than soil so that a practical assessment should also include considerations of geographic and many other aspects. Hence, as well as soil property information, other land information such as land use, fences and ownership data was also recorded. The importance of land use as well as soil depth and slope to soil conservation can be illustrated through their effects on water erosion. In the study area water erosion was more dominant than wind erosion because of the hilly country and the lack of cultivation. Figure 7 illustrates the importance of slope as it affects soil erosion.

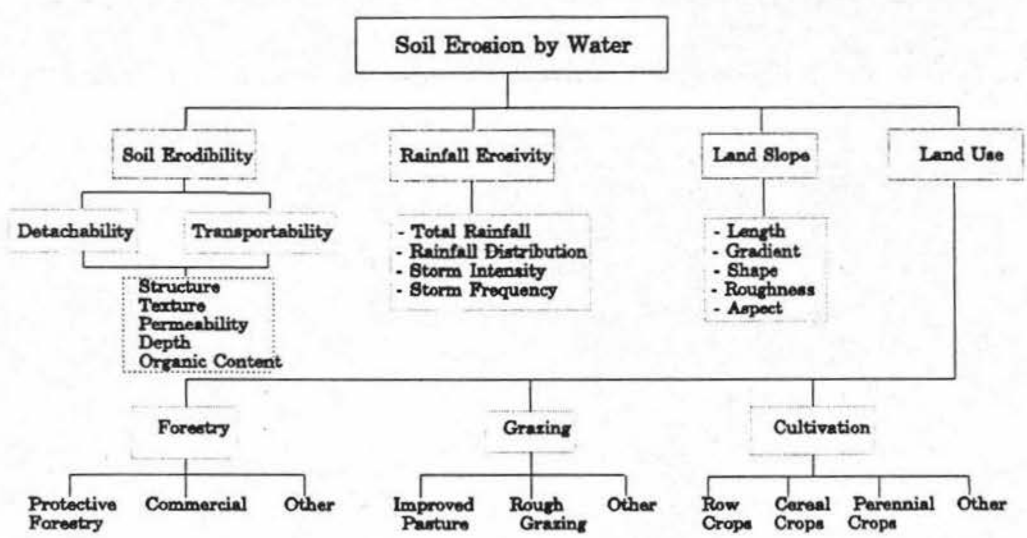


Figure 7 : Soil Erosion by Water (Sanders, 1986)

There are five important slope factors that directly influence soil erosion: length, gradient, shape, roughness and aspect (Sanders, 1986). However, existing land use in the study area is dominantly pastoral. Grass provides a dense and complete ground cover which provides a good protection against surface (sheet and rill) erosion. Thus shape and roughness are not critical. Gradient (angle of slope), however, is of prime importance, as runoff from steep slopes can cause sheet erosion and infiltration and sub surface flows can lead to landslide erosion on steep slopes having impermeable subsoil layers.

As well as soil type, structure, texture, permeability, soil depth and organic content are important. Information on these was collected during the soil data collection. In this study soil permeability was expressed as an internal drainage status, because permeability and internal drainage are considered to be similar although not identical qualities (Taylor and Pohlen, 1962).

Soil depth information is important not only because of its effect on soil erodibility but because of its function in determining available water holding capacity (AWC). The measurement of soil depth should not be confused with the solum. In many cases soil depth and solum are synonymous but sometimes they are not identical. For instance a soil formed from a thin layer of loam resting on stony gravels may have a thick solum with a well developed B horizon in the gravels, but agronomically this soil is considered to be shallow to moderate in depth.

Rainfall data was collected but it was not used for further analysis because of the homogeneity of distribution due to the smallness of the study area and lack of climate stations within the study area. Another parameter collected in the LRI which related to climate was elevation. Elevation affects temperature which affects suitability for particular kinds of crops. Elevation data was derived from DEM using PC TIN.

Existing erosion data was collected in the LRI in order to identify major agents affecting soil erosion. The major agent affecting soil erosion could be determined by indicating the physical condition of the areas which are the most severely eroded. This agent would be considered in determining management recommendations. This, together with other considerations such as the history of soil erosion, would be used in the land use capability classification and determining potential erosion.

The main objective of the rock type classification was to group rocks with similar erosion susceptibilities and characteristics (Crippen and Eyles 1985; Lynn and Crippen, 1991). As parent rock will directly influence parent materials, the rock type strongly determines the soil type in hill country. However, more than one kind of parent material may be formed from one kind of parent rock, so that more than one soil type can develop from one parent rock. Hence rock type identification in each land unit will help to determining soil type. Rock type data collected in this study was also used to determine potential erosion and thus conservation needs.

LRI Data Management

As discussed previously, the original scale of air photographs and existing maps is very important because it determines the level of detail of the data. Once this information had been digitized and all coordinates converted into map coordinates, the scale of the original data was lost and the data could be printed at any scale. Unfortunately, the GIS Software was not able to record the scale of the original data. Hence, in terms of data management it is important to record the scale of the original data separately.

As well as individual single factor map sheets, LRI factors can also be stored in multi-factor maps by combining them. However, overlying produces either many small polygons or gaps (slivers). Delineating map units having the same factors, which is usually done in reconnaissance scales of mapping, can avoid small polygons or gaps, but such map generalization is not appropriate for a detailed scale such as this study. Consequently, each LRI factor was individually mapped. At a detailed scale, the map generalization might be applied after all individual factors had been combined to produce a multi-factor map. As map generalization is a complicated process, it is greatly dependent on the accuracy of that multi-factor map.

Once the LRI factors have been stored in the database, they need to be made available for a multitude of uses while simultaneously ensuring the data is protected. This process is called a Database Management System and is discussed in many references (e.g Frank, 1988; Healy, 1990 and Star and Estes, 1990). Databases should provide modes of access for retrieval of information. Efficient retrieval operations are largely dependent on four factors: volume of data stored, method of data encoding, design of the database and the complexity of the query (Healy, 1990).

In order to make retrieval operations and analyses efficient, the volume, codings and size were reduced and simplified. To minimize the volume of data stored, databases were dissolved so that adjacent polygons which have the same values could be joined. To simplify data encoding, most values in the databases were expressed in numerical data. Finally, each item in the databases was kept in a minimum width to simplify design.

In summary, all LRI attributes were stored in individual map sheets and databases. Although individual map sheets took much more space in the computer, this form of individual map layers was needed to keep the original information. It could be argued that each individual map layer can be derived from the database. However, a map layer which was derived from the database would be less accurate than the original map layer because of map generalization that had been done after combining maps. Thus it could be concluded that the highest accuracy possible in any GIS product could not be better than the accuracy of the individual map layers.

Errors and Uncertainty in the LRI Data.

Errors in the applications of GIS are the basis of considerable discussion. Walsh *et al* (1987) considered there are two sources of errors: inherent and operational, which contribute to reductions in accuracy of the products that are generated by GIS. Thapa and Basler (1992) discussed accuracy of spatial data and identified errors in primary and secondary methods of data collection. Thus errors, either inherent errors from data sources or operation errors from combination input data, should be recognized in order to minimize the total errors.

LRI factors collected in this study were mainly primary data. This meant that most data was compiled from a combination of air photo-interpretation and field observations. Some references were treated for deduction. In terms of the primary methods of data collection, this introduced some errors : personal, instrumental and environmental errors (Thapa and Basler, 1992). In this study, these types of errors could not be separated nor quantified individually because they interacted with each other. The best method of recognizing these was by identifying the probability in which operational data collection would involve errors.

During field observation, errors could occur because of carelessness or inattention of the observer when using equipment or taking observations. This probably occurred in measurement activities (e.g measuring slope angle, soil depth) and observation mistakes could have occurred in determining of soil type, rock type and drainage status. Walsh *et al* (1987), Chrisman (1991) and Thapa and Basler (1992), consider errors due to carelessness or inattention are gross and systematic errors whereas incorrect observations are classified as random errors. Gross errors and systematic errors in LRI mapping were corrected by checking data observations immediately after data collection and by repeating measurements and checking for consistency. Random errors might result in missinterpolation of field phenomena. However, random errors in LRI data were checked by referring to references.

Errors were also possible when transferring data to the map. Carelessness in delineating and placements of points will introduce errors. To minimize these, the data was rechecked in the field. The maps contained inherent errors that can not be replaced. These are mainly due to the earth being spheroid so that any representation of the earth surface in a flat surface involves distortions.

Accuracy during delineation was dependant upon digitizing. Since digitizing involves manually encoding data, human factors may be involved. Errors can be due to tedium and the time involved. Human effects were investigated by Otawa (1987) on a square mile of soil map which had 24 polygons. The result showed that a majority of digitized polygons fell within a plus or minus 7% range from the mean. It clearly indicated that there are personal factors including style, habit and attitudes which affect accuracy. The accuracy of digitizing is affected by the skill of operator, more experienced operators will produce more precise digitized data. An advantage of the detailed scale was that because the area was small, the polygons were not too complicated and errors could therefore be minimized. Even so, checking of errors was still done by overlying the plot of the map over the original map at the same scale immediately after the map had been digitized. Errors that may have occurred during digitizing were also checked when constructing topology and editing operations by either using manual or automatic operations. Only node errors and label errors could be identified automatically, other errors were identified and fixed manually. In summary, manual digitizing will provide accurate digitized data for small areas, where the polygons are not too complicated. For more extensive areas with complicated polygons, the use of scanner devices may be a better choice.

Once data had been digitized, it needed to be transformed to real coordinates. Transformation of these maps could also introduce some errors, e.g because ground control points were not placed in the right real coordinates. However, these errors had been indicated by RMS.

Uncertainty in spatial databases can occur because the features contained in these databases were abstractions of real world phenomena. The uncertain data in LRI factors were mainly because the change of adjacent values occurred gradually. This occurred in the soil depth, soil type, rock type, drainage status, slope and existing erosion maps. However LRI factors which were individually mapped at a detailed scale were expected to minimize uncertainty, particularly in choropleth maps.

Technical Notes:

Significant technical notes made during data collection and data management in the LRI include:

1. The most dynamic factor in the LRI was present erosion data. This data should be periodically updated, depending on the annual rainfall distribution.

2. The RMS errors that indicated the accuracy of transformation was valuable information which had to be stored in particular text files. The files could be then used to show the level of accuracy. Macro commands (e.g SML) were able to do this operation.

3. The following limitations of PC TIN were found during the operations:
   - The area that would be developed to be a TIN had to be a rectangle.
   - TIN tended to remove data behind "hills" so that in a three dimension view, there wouldn't be lines behind the "hills".
   - Surface representation in fishnet lines were often broken in high z factors. Surface representation of diagonal lines, on the other hand, often had "unexpected lines" which had to be removed.
   - Draping polygon coverage onto TIN did not work properly.

4. A contour map was not appropriate to be developed for DEM. This might be because an excessive number of points was sampled along contours (oversampling) but no data was sampled across contours (undersampling). Hence, elevation point data, if available, was recommended to be used for DEM.

5. In terms of data display, PC ARC/INFO v3.4D had "polygon too complex" problems which was a limitation in printing polygons having more than 5000 vertexes. This could be solved by dividing big polygons into several

polygons. Warning of this problem would not appear in the map composition process but would come during printing operations.

6. PC ARC/INFO was unable to handle "dot shading" and "slash shading" when these types of shading were used to represent data values in polygon coverages.

CHAPTER IV

LAND USE CAPABILITY ASSESSMENT AND DEFINING POTENTIAL LAND USES

Introduction

The Land Use Capability Classification system was originally developed by the United States Department of Agriculture during the 1930s as part of a programme to control soil erosion (Norton, 1939). It was further developed by Klingebiel and Montgomery (1961).

In New Zealand, the use of the LUC classification system for soil conservation planning began in 1953. Since being introduced, it has been modified to suit New Zealand conditions (SCRCC, 1971). Despite similarities in objectives with the USDA system, the primary modifications made changed the emphasizes from an interpretation of soils to one of interpreting the land. Land is taken to include all those physical factors affecting long term management. LUC classifications for all regions of New Zealand are now available following the New Zealand land resources inventory (NZLRI) that was undertaken from 1973 to 1979. This survey was first published at a scale of 1 : 63 360 but updates are now prepared at 1 : 50 000.

The LUC assessment at the detailed scale in this study enabled map units to be classed as suitable for different land uses, i.e. cropping, high potential for pasture, low potential for pasture, exotic forest and reserves. This information could be used to make recommendations for land management options. These would be combined with soil conservation needs to develop farm soil conservation plans.

Land Use Capability Assessment

Concepts and Assumptions

Land use capability is "the systematic arrangement of different kinds of land according to those properties that determine its capacity for permanent sustained production" (SCRCC, 1971). The land is classified on the basis of permanent physical limitations. These are physical characteristics which adversely affect the capability of the land and which cannot be easily changed. The definition indicates clearly that there are two basic concepts involved in the assessment: capability and limitations.

Capability means the potential of land for use in specified ways, or with specified managements (Dent and Young, 1981). There are several types of land use assumed in the classification:

a. Arable use for a wide range of crops and without the need for soil conservation practices.

b. Arable use with restrictions limiting the choice of crops and requiring soil conservation practices.

c. Pastoral use.

d. Pastoral use with production woodlots.

e. Forestry

f. Protection purposes.

Class I land is the most versatile with the fewest physical limitations. While it is commonly used for intensive cultivation it may also be used for a wide range of other uses. Class VIII, on the other hand, should be used only for protection purposes. From Class I to class VIII the degree of limitations and hazards increases with a consequent reduction in sustainable land use opportunities (Figure 8).

The capability expressed in the classification does not necessarily indicate the best nor the most profitable use of the land. Instead it indicates the range of sustainable uses to which the area can be applied. Hence, areas defined as being capable of arable use may also be planted in a high value timber crop or put to some other non-arable use.

There are two kinds of physical limitations: permanent and temporary (Dent and Young, 1981 and Fletcher, 1987). Vink (1975) added a third: moderate limitations. Basically, the limitations are grouped according to their vulnerability to change. In this system land is classified according to its permanent limitations. A parcel of land may be assigned to a particular LUC class because of the total degree of physical limitations that cause a significant decrease in the land's capability.

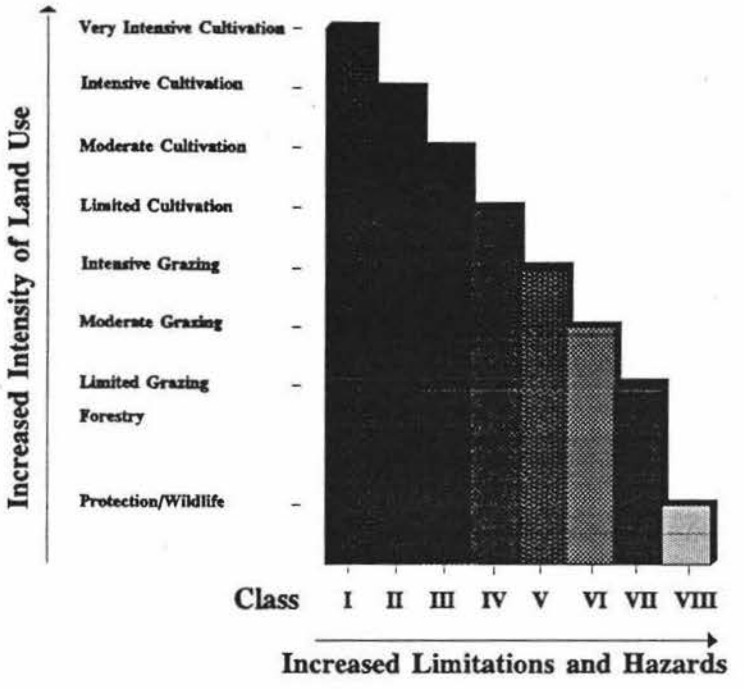


Figure 8 : A basic concept of the land use capability classification

Some assumptions that were used in defining LUC are:

1. The classification was based on permanent limitations of the land. Thus, temporary limitations were not considered.
2. It was not a rating for specific crop productivity.
3. The system did not indicate the most profitable use that could be made of the land.
4. Ownership and management skills were not taken into account.
5. Management of land was assumed to be at an above average level.
6. Location and accessibility were not taken into account.

7. A long term economic trend was considered. Land which could be improved but on which a large expenditure would not be justified, could not be placed in classes I-IV i.e improvements had to be within the capability of an individual farmer.

Structure of Classification

Conventional techniques of LUC classification use three categories: the class, subclass and unit. The highest level of the classification is the LUC class. Land use capability classes are arranged in order of increasing degree of limitations or hazards, whereas capability subclasses are subdivisions of LUC classes which show the dominant physical limitation. Finally, LUC units are map units that have similar soil characteristics, potential productivity and management requirements, and require the same soil conservation measurements.

The New Zealand Land Use Capability Classification System, has eight LUC classes, the first four are categorized as arable lands and the second four are as non arable lands. Four subclasses are recognized: erosion (e), wetness (w), soil limitations within the rooting zone (s), and climate (c) (SCRCC, 1971). Classes are indicated by roman numerals while small letters are used to express sub classes. (However, in computer operations Greek numerals were still used because Roman numerals cannot be sorted on a computer). Thus if a particular area is classified as LUC class IIIw, it indicates that the area has moderate limitations to arable use and the dominant physical limitation is wetness. The LUC class descriptions can be found in references related to the land use capability classification: Taylor and Pohlen, 1962; SCRCC, 1971; Ministry of works, 1979; Fletcher, 1987.

Because of the way the classes are defined, not all subclasses can be applied to each class. Subclass e, for instance, does not apply to classes I or V. Thus in this study class V is allocated to areas not suitable for cultivation because of reasons other than erosion hazards (e.g. steep stable sandstone hills or stable limestone slopes). The relationship of subclasses to classes is illustrated in Table 2.

Table 2: Sub classes which are applicable to each LUC class. (SCRCC, 1971)

LUC CLASS	**SUBCLASSES**			
I		w,	s,	c
II	e,	w,	s,	c
III	e,	w,	s,	c
IV	e,	w,	s,	c
V		w,	s,	c
VI	e,	w,	s,	c
VII	e,	w,	s,	c
VIII	e,	w,	s,	c

Note : The sequence of subclasses follows the order of priority in the classification

For farm soil conservation planning, the LUC classification was not the prime objective, instead its purpose was to group areas with similar potentials and limitations so that the final product of a map showing recommendations for land management practices could be prepared. Since the LUC unit is used in reconnaissance scales of mapping to generalize mapping units that have similar management requirements, the writer considers they are not applicable in this scale of analysis because factors considered for LUC units are not sufficiently varied in a small study area. Management requirements will be shown later, in the recommendations, after consideration of some other factors which were collected in more detailed mapping. Hence, the LUC unit was not applied in this study.

The Use of the GIS for LUC Assessment

The concepts and assumptions which have been described in the above discussion should be obvious in the classification. Further, the structure of classification follows the conventional structure that was discussed previously.

In general, there are two tasks in defining LUC: creating criteria related to the condition of the study area and delineating areas which meet with the criteria. The procedure of using GIS operations to apply the criteria for the classification is discussed below.

Assessment Procedure

Land can be evaluated either directly or indirectly. Direct evaluation is usually done by setting up experiments at particular sites. The evaluation is then carried out according to the interaction between site characteristics and the treatment. The result is usually applicable only to the specific trial sites and for that treatment. Much more common, however, is indirect evaluation. This assumes that some inherent properties of land influence the success of a particular land use in a reasonably predictable manner. The LUC classification in this study was assessed on the basis of indirect evaluation.

There are two broad systems of indirect evaluation: categoric systems and parametric systems. Categoric systems group land into classes based on properties which are considered to be permanent limitations. These systems are implemented by testing land and soil properties against a set of criteria for each class. Parametric systems, on the other hand, combine the land and soil properties in a mathematical formula. Some of the advantages and disadvantages of these systems were discussed in detail by Mc Rae and Burnham (1981). In short, parametric systems are simple, appear to be objective and are easily applied, whereas categoric systems are considered more realistic. Based on these considerations, it was decided to use the principles of categoric systems for this study. Thus a set of criteria had to be created for the assessment.

Factors which were considered in developing criteria for the LUC classification in this study were: rainfall, elevation, slope angle, soil depth, drainage status and erosion hazard. Erosion hazard was derived from existing erosion data in the LRI together with other considerations such as percentage of soil profile lost and affected area. This was a subjective assessment but the data could also be considered as an erosion factor for the classification. Rainfall data was not taken into account because in the small study area rainfall distribution was presumed to be homogeneous as there were no records to prove otherwise. The elevation criterion was divided into below 600 m and above 600 m based on local farmers experience. Farmers considered areas above 600 m were not arable due to long periods of low soil and air temperature. The set of criteria used for the assessment is listed in Table 3. The LUC classification operations were performed within TABLES (the ARC/INFO database management system). Consequently, those factors which were used in the calculation had to be put in a single coverage which was achieved using the ARC/INFO UNION command.

Application of the criteria in selecting the appropriate classes and subclasses was carried out using the ARC/INFO simple macro language (SML). An example of SML commands that were used in the classification is shown in Appendix 2. The SML command was then run in TABLES. The results of class and subclass assessments were put in the "class" and "subclass" items respectively in the attribute table. Finally, the LUC Classification map was produced using the DISSOLVE command based on the related column(s). If the map contained either gaps or slivers, editing was carried out using principles of map generalization.

Table 3: Set of Criteria for the LUC Classification.

Class/Subclass		Slope Angle	Soil Depth*	Erosion Hazard.	Elevation	Drainage Status
I	w	A	> 90 cm	None	< 600 m	Moderate
	s	A	> 90 cm	None	< 600 m	Excessive
	c	A	> 90 cm	None	< 600 m	Well
II	e	B	46 - 90 cm	Slight	< 600 m	Very poor - well
			> 90 cm	Slight	< 600 m	Very poor - well
	w	A	46 - 90 cm	None	< 600 m	Imperfect - moderate
		B	> 90 cm	None	< 600 m	Imperfect - moderate
	s	A	46 - 90 cm	None	< 600 m	Excessive
		B	46 - 90 cm	None	< 600 m	Excessive
			> 90 cm	None	< 600 m	Excessive
	c	A, B	46 - 90 cm	None	< 600 m	Well
		B	> 90 cm	None	< 600 m	Well
III	e	B	16 - 45 cm	Slight	< 600 m	Very poor - well
		C	> 45 cm	Slight - moderate	< 600 m	Very poor - well
	w	A	16 - 45 cm	None	< 600 m	Imperfect - moderate
			46 - 90 cm	None	< 600 m	Very poor - poor
			> 90 cm	None	< 600 m	V. poor - imperfect
		B	16 - 45 cm	None	< 600 m	Imperfect - moderate
			> 45 cm	None	< 600 m	V.poor - imperfect
		C	> 45 cm	None	< 600 m	V.poor - imperfect
	s	A	16 - 45 cm	None	< 600 m	Excessive
		B	16 - 45 cm	None	< 600 m	Excessive
		C	> 45 cm	None	< 600 m	Excessive
	c	A	16 - 45 cm	None	< 600 m	Well
		B	16 - 45 cm	None	< 600 m	Well
		B	> 45 cm	None	< 600 m	Moderate
		C	> 45 cm	None	< 600 m	Moderate - well
IV	e	C	16 - 45 cm	Moderate	< 600 m	Very poor - well
		D	> 15 cm	Moderate	< 600 m	Very poor - well
	w	A, B	16 - 45 cm	None	< 600 m	Very poor - poor
		C	16 - 45 cm	None - slight	< 600 m	V.poor - imperfect
	s	C	16 - 45 cm	None - slight	< 600 m	Excessive
	c	C	16 - 45 cm	None - slight	< 600 m	Moderate - well
V	w	A	0 - 15 cm	None		Very poor - imperfect
			> 15 cm	None	> 600 m	Very poor - imperfect
		B	0 - 15 cm	None - slight		Very poor - imperfect
			> 15 cm	None - slight	> 600 m	Very poor - imperfect
		C	0 - 90 cm	None - slight	> 600 m	Very poor - imperfect
		D	> 15 cm	None - slight		Very poor - imperfect

Class/Subclass		Slope Angle	Soil Depth*	Erosion Hazard.	Elevation	Drainage Status
V	s	A	0 - 15 cm	None	< 600 m	Moderate - excessive
		B	0 - 15 cm	None - slight	< 600 m	Moderate - excessive
		C	0 - 15 cm	None - slight	< 600 m	Moderate - excessive
		D	> 15 cm	None - slight	< 600 m	Moderate - excessive
		E	> 15 cm	None - slight	< 600 m	Moderate - excessive
	c	A	0 - 90 cm	None	> 600 m	Moderate - excessive
		B	0 - 90 cm	None - slight	> 600 m	Moderate - excessive
		C	0 - 90 cm	None - slight	> 600 m	Moderate - excessive
		D	> 15 cm	None - slight	> 600 m	Moderate - excessive
		E	> 15 cm	None - slight	> 600 m	Moderate - excessive
VI	e	D	0 - 15 cm	Moderate		Very poor - well
		E	> 15 cm	Moderate - severe		Very poor - well
		F	> 15 cm	Moderate		Very poor - well
		G	> 15 cm	Moderate		Very poor - well
	w	D	0 - 15 cm	None - slight		Very poor - imperfect
		E	0 - 15 cm	None - slight		Very poor - imperfect
		F	> 15 cm	None - slight		Very poor - imperfect
	s	D	0 - 15 cm	None - slight	< 600 m	Moderate - excessive
		E	0 - 15 cm	None - slight	< 600 m	Moderate - excessive
		F	> 15 cm	None - slight	< 600 m	Moderate - excessive
	c	D, E	0 - 15 cm	None - slight	> 600 m	Moderate - excessive
		F	> 15 cm	None - slight	> 600 m	Moderate - excessive
VII	e	F	0 - 15 cm	Moderate - severe		Very poor - well
			> 15 cm	Severe		Very poor - well
		G	0 - 15 cm	Moderate		Very poor - well
			> 15 cm	Severe		Very poor - well
	w	F	0 - 15 cm	None - slight		Very poor - imperfect
		G	> 15 cm	None - slight		Very poor - imperfect
	s	F	0 - 15 cm	None - slight		Moderate - excessive
		G	> 15 cm	None - slight		Moderate - excessive
	c	F	0 - 15 cm	None - slight	> 600 m	Moderate - well
		G	> 15 cm	None - slight	> 600 m	Moderate - excessive
VIII	e	G	0 - 15 cm	Severe - very severe		Very poor - excessive
	w	G	0 - 15 cm	None - slight		Very poor - imperfect
	s	G	0 - 15 cm	None - slight	< 600 m	Moderate - excessive
	c	G	0 - 15 cm	None - slight	> 600 m	Moderate - excessive

* The depth of cultivable soil material upon the underlying rock, stones, or other strongly contrasting layer (see Chapter III)

Defining Potential Land Use

The land capability system can be adapted to show the potential of land for particular uses. Based on the basic concepts of the classification (Figure 8), the capability class groups those areas having similar capabilities for sustained use. In general, LUC classes I to IV are capable of cropping while classes V to VII are not, but they are capable of pastoral farming or forest use. Class VIII should be used only for protection purposes. The increase in class can be interpreted as reducing potential land use. Hence, in a simple way, the broad potential land use can be directly derived from the LUC classification by examining the capability classes and subclasses.

In this study, the potential land use can be defined using database analyses. Again, a set of criteria was needed to perform the operation. Additional factors, can be added in the database either if necessary by combining the multi-factor map with other maps related to the new factors or by adding to the information in the database. In this case, operations to define potential land use were similar to the operations used in the LUC classification.

Potential land use classes could also be identified by combining each factor after selecting requirements from individual maps. Areas that have a potential for cropping, for instance, could be derived using the following set of requirements:

- soil depth more than 20 cm
- slope angle less than 20 degrees
- elevation below 600 m asl
- drainage status no worse than imperfectly drained.

A flow chart of operations used to select areas suitable for cropping is shown in Figure 9. Obviously different potential land uses have different requirements. Thus, a list of requirements for a specific land use is needed to perform the operations.

Results and Discussion

Results of the Assessment

As discussed in chapter III, the results of an analysis can be displayed in a tabular form or as a map. The result of the analysis described in the previous section is shown in table 4. This table also illustrates the physical factors on which LUC class and subclass were based.

The LUC map derived by dissolving class and subclass items is displayed in Figure 10. Because of the limitations of the Paintjet colour printer, the shading in this map could not be matched with the standard colours that are used in the LUC classification (SCRCC, 1971). The red colour shading which is used for LUC class III was altered to blue, and red was used for LUC class VI instead of orange.

Statistics for each class and subclass of the LUC Classification are shown in Table 5. Differences in the number of polygons before and after dissolving, as well as the total area before and after eliminating, show the generalizations that occurred to produce this map. As the dissolving process removes boundaries between adjacent

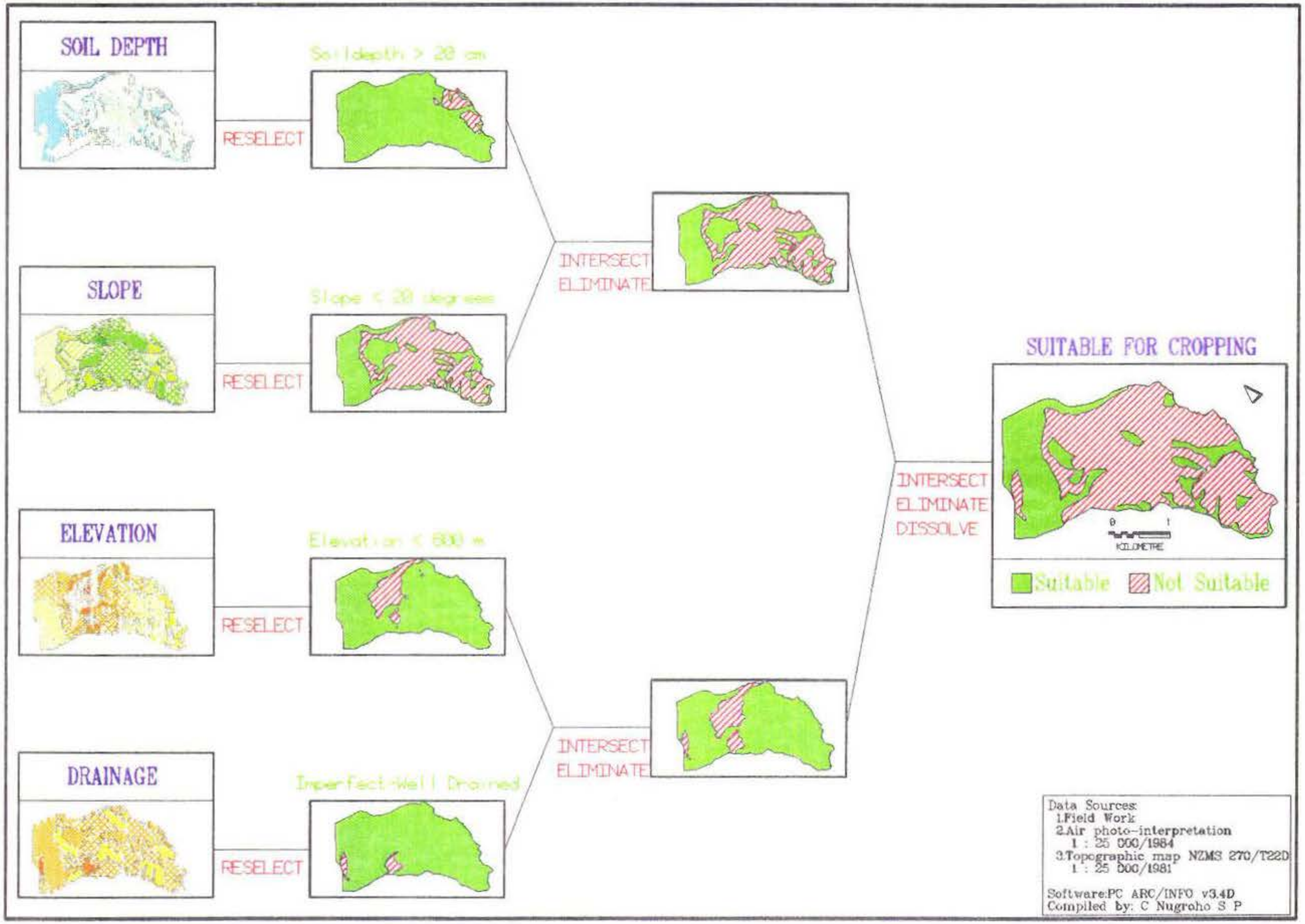


Figure 9 : Flowchart of operations to select areas suitable for cropping

AREA	PERIMETER	COVLUC_	COVLUC_ID	SLOPECO	DEPTHCO	EROSHAZ	ELEV	DRAINCO	CLASS	SBCL
89303.0600	1341.9330	129	128	1	4	1	1	4	1	w
66144.1900	1931.4740	57	56	2	3	1	1	5	2	c
547730.1000	4379.5420	2	1	1	4	1	1	3	3	w
489347.6000	3733.6790	7	6	1	4	1	1	3	3	w
25404.1300	1044.6510	457	456	3	3	1	1	4	3	c
29775.0000	1130.7660	534	533	3	4	1	1	4	3	c
36591.5600	1924.7430	10	9	4	2	3	1	4	4	e
14857.6900	778.2170	91	90	4	2	3	1	3	4	e
11678.0000	476.8781	100	99	4	2	3	1	5	4	e
17639.8800	886.5937	369	368	4	3	3	1	2	4	e
25427.0600	1164.7740	387	386	4	2	3	1	2	4	e
12395.5000	1167.7560	512	511	4	4	3	1	4	4	e
10939.1900	488.3441	498	497	3	2	1	1	4	4	c
10728.9400	534.7299	509	508	3	2	1	1	4	4	c
15702.9400	654.2563	667	666	3	2	2	1	5	4	c
71661.3100	1500.4220	46	45	3	2	1	1	3	5	w
55910.2500	1053.6400	446	445	4	2	2	1	4	5	s
30123.5600	1023.9430	147	146	2	3	1	2	5	5	c
82743.0000	2644.8580	276	275	5	2	3	1	3	6	e
82262.8800	3611.6250	295	294	5	2	4	1	5	6	e
61457.1900	2482.9980	411	410	5	2	3	1	4	6	e
60206.3100	1100.0690	460	459	4	1	3	1	4	6	e
57888.0600	2816.0220	695	694	5	2	3	1	4	6	e
97465.0600	3192.0440	696	695	5	2	3	1	4	6	e
41677.0000	1570.1890	448	447	5	1	2	1	3	6	w
11199.1900	868.0129	490	489	5	1	2	1	3	6	w
20881.8100	1251.8810	155	154	6	2	2	1	4	6	s
27522.5600	955.5085	586	585	5	1	2	1	5	6	s
45176.1300	1032.2480	590	589	5	1	2	1	5	6	s
61439.0000	1953.2530	105	104	6	2	4	1	5	7	e

NOTES :

AREA in sq. metres; PERIMETER in metres.

COVLUC_ = Internal Id; COVLUC_ID = Users Id

SLOPECO = Slope Class
1 = 0 - 3 degrees; 2 = 4 - 7 degrees; 3 = 8 - 15 degrees; 4 = 16 - 20 degrees
5 = 21 - 25 degrees: 6 = 26 - 35 degrees: 7 = > 35 degrees

DEPTHCO = Soil depth
1 = 0 - 15 cm; 2 = 16 - 45 cm; 3 = 46 - 90 cm; 4 = 91 - 120 cm

EROSHAZ = Erosion Hazard
1 = None ; 2 = Slight; 3 = Moderate; 4 = Severe; 5 = Very severe

ELEV = Elevation
1 = below 600 m; 2 = above 600 m.

DRAINCO = Drainage Condition
1 = Very poorly drained; 2 = Poorly drained; 3 = Imperfectly drained
4 = Moderately drained; 5 = Well drained; 6 = Excessively drained

CLASS = LUC Class

SBCL = LUC Subclass
e = erosion; w = wetness; s = soil; c = climate

Table 4: The polygon attribute table (PAT) of the multi-factor map showing operations of LUC classification

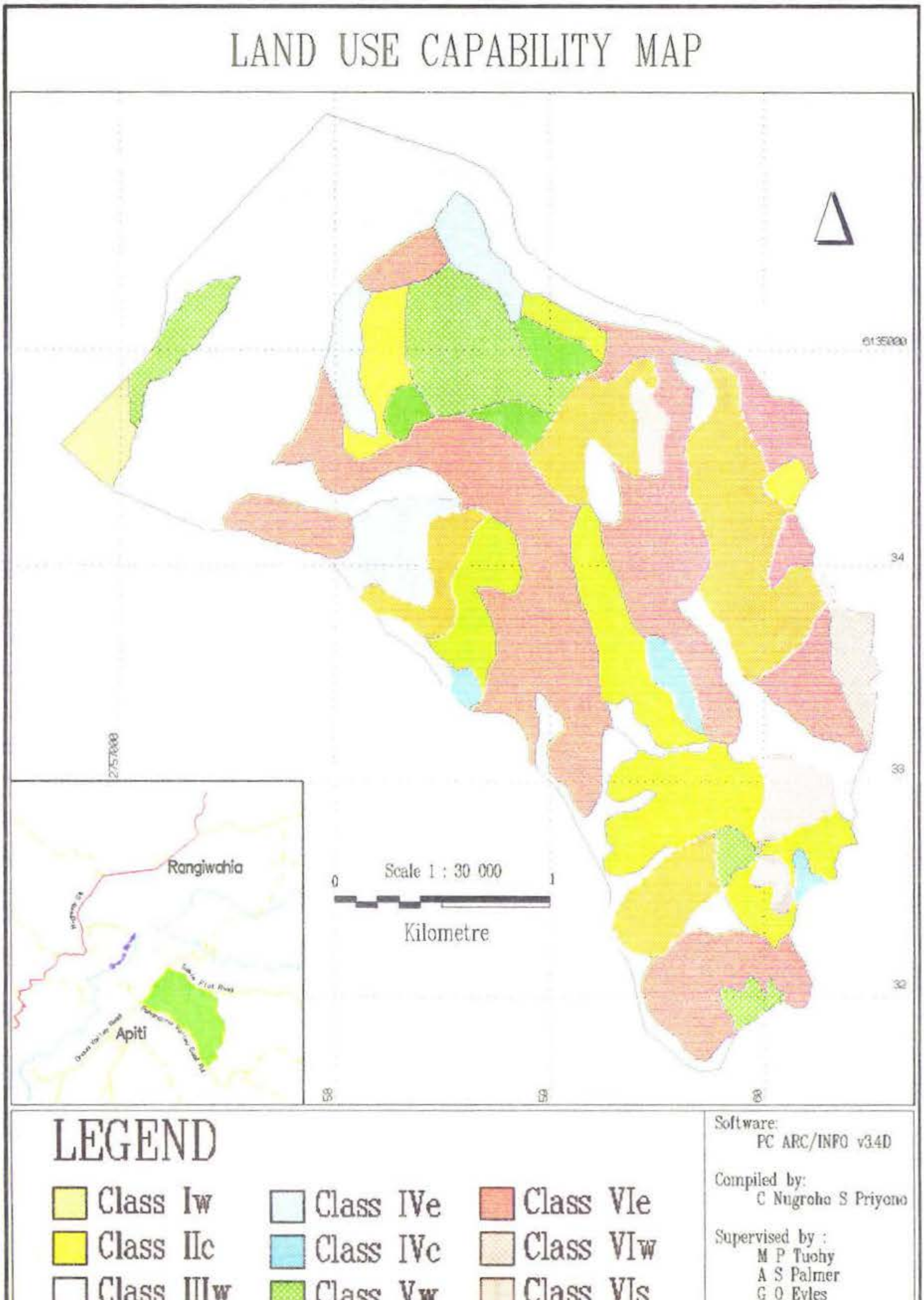


Figure 10 : Land use capability map

polygons having the same value, the combination that derives the value cannot be identified. If that identification is required, it can be done only on the original coverage. The eliminating process joins small polygons to adjacent bigger polygons. Thus, this process has to be done carefully because there may be small "unique" polygons which must be preserved.

Table 5: Total area of LUC class and subclass in the study area *

LUC Class/Subclass		Number of Polygons		Total Area (ha)	
		Before Dissolving	After Dissolving	Before Eliminating	After Eliminating
I	w	1	1	8	9
II	c	6	2	15	17
III	c	12	3	9	10
	w	91	4	201	204
IV	c	13	2	6	4
V	c	19	3	15	15
	s	220	9	180	177
	w	114	10	115	112
VI	e	123	6	108	108
	s	15	3	18	18
	w	15	1	8	7
VII	e	82	4	78	79
	s	9	2	14	15
Total		720	50	775	775

* Data was derived using the ARC/INFO STATISTIC command (Appendix 3).

Discussion

There are various interpretations of the terms "capability" and "suitability". FAO (1976) used "suitability" instead of "capability" because of the differences in interpretation. Vink (1975) considered that there are no essential differences between land suitability and land capability. However, in the writer's opinion, land capability is different to land suitability and the terms should not be confused. Land capability refers to the land's capability for a range of uses, e.g agriculture, forestry or recreation. A capability assessment usually also involves some suitability judgements, e.g this land is unsuitable for arable crops or improved grassland, but it is suitable for rough grazing or for forestry. Land suitability, on the other hand, refers to tightly defined specific uses (often related to specific crops) e.g suitable for maize or golf courses.

The LUC Classification is a simple system and easy to present. The concept of limitations and its application using a table of criteria is simple in principle and easily applied in the field. It clearly indicates major problems, which are expressed in limitations, that have to be overcome. The classification also enables planners to answer questions such as how much arable land is in a particular area and where it is, or where the areas are that have erosion or drainage problems. These types of questions are easily answered because the result of the classification can be clearly displayed on maps and tables. However, it should be realized that boundaries between different categories, particularly between classes are often transitional. Moreover, the classification will not be able to grade each class. Consequently, the classification cannot explain whether one particular map unit class III land is better or worse than other class III areas.

Despite the simplicity of the classification, it has some limitations which were identified during this study. Firstly, the LUC classification was unable to take into account interactions between different physical limitations, particularly if a set of criteria had been established. The classification could not determine which factors were near the lower boundary of a class but having no single limitation sufficiently severe to require downgrading to a lower class. This case occurred in the study area. In most soils developed from interbedded sandstone-siltstone at lower altitudes, soil slip often occurs on the steep slopes with imperfect drainage. Frequent soil slips were found, however, in some areas with imperfectly drained soils but only moderate slopes. In this particular case, the major limitation was difficult to define because both phenomena (erosion and wetness) were equally dominant. To resolve this difficulty, the limitation was decided following the sequence of priority. Since erosion was a more severe limitation, it was considered to be the major limitation.

The LUC Classification does not distinguish between "the best" soils, which have no limitations for general arable use, and "unique" soils, that are only suitable for particular land use although they may have limitations for arable use. Unique soils require specialised management, but under such management they can be more profitable than either "the best" soils or those which would be placed in a higher capability class.

The LUC criteria in Table 3 cannot be extrapolated to other areas which have different conditions. Micro climate and rock type are perhaps the most important features to consider. The criteria for sand country will be different to the criteria for loess mantled areas. Thus, the table is suitable only for areas which have soils developed from interbedded sandstone-siltstone and loess, and a micro climate influenced by hill country with high annual rainfall. Using the GIS, adjustment of criteria for different areas can be simply done by altering the SML commands. Reclassification is then a straightforward procedure.

The climatic limitation was difficult to identify in this classification because climate parameters, such as temperature and rainfall, were not regarded as variables because of the small size of the study area and the lack of climate data. It was stated that the area is warm in the summer and cold in the winter due to the high elevation. As plants vary widely in their tolerance to temperature local farmers regard this factor as important. The area can be compared to other areas which have similar micro climates and parent rocks such as near Ohakune or Raetahi where specialised cropping is practised. Despite the relatively high altitude (600 m) and cooler environment, the excelent physical properties of the Ohakune soils and the plentiful rainfall make them highly suited to crops such as carrots (Molloy, 1988). However, according to the farmers in the study area, long periods of low temperature in the winter reduce the growing period for crops particularly those areas above 600 m. Based on this local experience, it was decided that climate will be major limitation in areas more than 600 m asl.

Since the GIS can be used as a "planning simulator", the result of analyses can be tested in the field. In the LUC classification, there were no particular principles of classification that had to be followed because it is an "ad hoc" system. The criteria used to select LUC class and subclass were selected only after a ground survey. The advantage of using GIS is that any modifications to the classification can be achieved by simply altering the selection criteria.

Despite its weaknesses, the classification was able to indicate both the capability of the land for sustained use and the major problems related to soil conservation and management. The overall level of capacity for sustained use is expressed in the LUC Class, whereas the major problems/limitations are expressed in LUC Subclass. Such information is very useful when determining recommendations for land management practices and is an important step in the overall process of farm soil conservation planning.

A LUC map can be produced in the GIS by intersecting single factor maps according to criteria which select various combination of features from the associated databases. The selection can be done using ARC/INFO commands SELECT and ASELECT. However, since overlying maps in a vector data structure is a very complicated task it uses a great deal of memory. For instance a combination of four single factor maps in this study area, where each single factor map requires 30 000 to 50 000 bytes, produces a multi factor map with storage requirement of 400 kilo bytes. The increasing memory requirements reduces the speed of the computer. Direct analysis in a database, on the other hand, is a more simple task and thus it uses fewer characters. For these reasons, the LUC classification was carried out using a combination of map overlay and database analyses. The database was created by overlying single factor maps with the classification undertaken in the database to minimize characters.

Overlying the four single factor maps also resulted in many small polygons, gaps and slivers. Combining single factor maps of 37 to 66 polygons produced 710 polygons in the multi-factor map. This increase occurred because the maps were almost identical due to the difference in digitizing time and operators. Editing was needed using map generalization to improve the quality. In terms of cartography, map generalization is a fundamental but complex process, because it often involves a considerable amount of intuition and a detailed knowledge of the study area. Editing the LUC map was carried out using the principles of map generalization which have been discussed in detail by Brassel and Weibel (1988), and Weibel and Buttenfield (1992).

CHAPTER V

POTENTIAL EROSION ASSESSMENT AND DEFINING CONSERVATION NEEDS

Introduction.

In addition to the land use capability classification, it was considered important in this study to separately assess the land in terms of its vulnerability to erosion. It was assumed that areas having a high potential for erosion would also be the most fragile in terms of sustained production from the land. Thus, conservation needs could be determined according to that information. This part of the study aimed to delineate regions which were vulnerable to erosion and for these to recommend appropriate soil conservation practices.

Potential erosion was assessed as one of four categories: none, slight, moderate and high. Areas of potential erosion were delineated according to various combinations of the physical features which had been previously mapped. However, areas having the same potential might require different conservation practices. Hence, conservation needs were then derived for individual areas according to the parameters upon which the potential erosion classification was based. The resulting maps show the land classified in terms of potential erosion and recommended conservation practices for each area.

Basic Principles of the Assessment

The erodibility of a soil is its vulnerability or susceptibility to erosion that is the reciprocal of its resistance to erosion (Hudson, 1981). A soil with a high erodibility will suffer more erosion than a soil with low erodibility if both are exposed to the same rainfall. The assessment of erodibility is complicated because it depends upon many factors. However, the factors can be divided into three groups: physical features of soils, topographical features and management of land.

The relationship between soil physical and chemical properties and erodibility has been investigated by many workers. Bouyoucos (1935), for instance, suggested an index of erodibility which relied on soil texture. He also recognised that the resistance to water erosion can be linked with the degree of aggregation of soil particles and the stability of aggregates, but aggregate stability is not easily measured. To substitute some more easily measured properties, Wishmeier (1978) introduced four dominant factors affecting erodibility, namely: organic matter content, soil particles, structure and permeability.

The amount of water in a soil also has a great effect on erosion. A compacted surface inhibits infiltration, consequently excess water will flow over the surface. This surface runoff can lead to either sheet or rill erosion under the right conditions. On the other hand, subsurface runoff, due to impermeable layers in lower horizons on steep land may lead to failure in the top layers of soils resulting in soil slip or slump erosion. These facts clearly show that inherent characteristics of soils can have considerable effects on soil erodibility.

Topography also influences erosion, generally steep land is more vulnerable than flat land because erosion processes such as splash, scour and transport have a greater effect on steep slopes.

The difference in erosion caused by different management of the same soil can be very much greater than any difference in erosion arising from the same management of different soils. Erodibility is influenced more by management than by any other factors.

The discussion above implies that inherent characteristics of soils, slope angle and land use are important factors that should be taken into account in defining potential erosion. Any such assessment should be based on combinations of these factors. Since inherent characteristics of soils are derived from parent materials, rock type and soil type data may be used in place of some detailed soils data in determining potential erosion. These factors had been collected in the land resources inventory (Chapter III).

Many erosion types are recognized in New Zealand with the main types described in detail by Eyles (1985). In this particular study, only a few types occurred. As the study area is dominated by pastoral use, surface erosion by water due to particle movement was not extensive. That is because the impact of rainfall on the soil surface is reduced by the almost complete vegetative cover. However, mass movement erosion tends to be more dominant. The combination of steep slope, weakly compacted parent material and high rainfall intensities are the main factors causing movement. Thus, the potential erosion assessment in this study was an assessment of the potential for soil slip or slump erosion. In defining conservation needs, however, other erosion types such as wind and streambank erosion were also considered by estimating the vulnerability to the erosion types based on field observations.

Assessment Procedure

The assessment was based on factors that had been collected in the LRI, namely: slope angle, rock type, soil type and land use. With land use in the study area dominated by pastoral use with only small patches of native scrub and woodlots, the land management was not varied. Because of this, the land use factor was not taken into account in the assessment.

Only those combinations which occurred in the field were considered. For example, loess was found only on flat or rolling land, not on steep slopes, while interbedded sandstone-siltstone and limestone-sandstone, were not mapped on flat land because they were covered by loess or alluvium.

Since one rock type may have more than one soil type develop into it, these combinations were also considered. Table 6 shows the relationship between soil type and the rock type from which they were derived.

The assessment was carried out using factors from the LRI as well as by field observation to confirm these combinations. Field observation was also used to confirm the feasibility of these combinations before the criteria were applied.

The criteria that were used are shown in Table 7.

Table 6 : Soil types in the study area and rock types from which they are derived.

Rock Type	Soil Type
1. Alluvium/colluvium	Utuwai silt loam
2. Loess and tephra	Dannevirke silt loam, Dannevirke silt loam, rolling phase Kiwitea fine sandy loam, rolling phase.
3. Interbedded sand-siltstones	Whetukura silt loam Whetukura hill soils
4. Interbedded lime-sandstones	Whetukura silt loam Whetukura hill soils

The GIS procedure used to assess potential erosion was similar to that described for the LUC classification in Chapter IV. All necessary factors were combined into a single database. PC Overlay's UNION command was used to combine the factors from the individual maps. Database analysis was then carried out using SML commands which sorted the database according to the criteria (Appendix 4). The operations are displayed in Figure 11.

The potential erosion map was produced by dissolving the multi-factor map on the basis of items relevant to the purpose of the map. In this case, the DISSOLVE command was executed using two items: proneros and comb. (proneros = column for potential erosion; comb = column for combinations of the factors). This map showed not only the level of potential erosion but also the

Step I : Creating Criteria

Potential Erosion	Slope Angle	Rock Type	Soiltype	Comb
Not Susceptible	A,B	Alluvium-Colluvium	Ut	1
		Loess	D	2
Slight	C, D	Interbedded Sand	Wt	3
		Int. Limestone	Wt	4
		Loess	DR, KwR	5
Moderate	E	Interbedded Sand	WtH	6
		Int. Limestone	WtH	7
High	F, G	Interbedded Sand	WtH	8
		Int. Limestone	WtH	9

Step II : Creating SML Commands

```
sel erospot.pot

&rem Not Susceptible to erosion
resel slopeco in (1,2) and rocksco = 4 and soilco = 6
calc proneros = 1
calc comb = 1
asel
resel slopeco in (1,2) and rocksco = 2 and soilco in (1,2)
calc proneros = 1
calc comb = 2
asel
-
-
&rem High Susceptibility to Erosion
resel slopeco in (6,7) and rocksco = 3 and soilco in (3,4)
calc proneros = 4
calc comb = 8
asel
resel slopeco in (6,7) and rocksco = 5 and soilco = 3
calc proneros = 4
calc comb = 9
asel
```

Step III : Running the SML commands in TABLES

AREA	PERIMETER	EROSPOT_	EROSPOT_ID	SLOPECO	ROCKSCO	SOILCO	PRONEROS	COMB
1068666.0000	6684.5300	2	1	1	2	1	1	2
31800.3100	1442.6960	3	2	1	2	2	1	2
46600.1300	1823.5110	7	6	5	3	4	3	6
20833.0000	734.4282	8	7	2	2	1	1	2
13472.3800	893.8190	10	9	2	2	2	1	2
63758.6900	2047.1640	12	11	2	4	6	1	1
98277.4400	1850.1900	13	12	4	3	3	2	3
101353.8000	3173.6470	15	14	3	2	1	2	5
161290.9000	2295.8310	16	15	4	2	1	2	5
94000.3800	1672.1210	22	21	7	3	4	4	8
81280.2500	1622.6460	30	29	6	3	4	4	8
64936.4400	1315.1200	31	30	6	3	4	4	8
467827.2000	4381.8170	32	31	4	2	1	2	5
396590.1000	6310.0700	39	38	6	5	3	4	9
92580.3100	1448.8360	41	40	5	5	3	3	7
44134.1300	1045.8000	42	41	4	2	5	2	5
247877.1000	2113.1770	49	48	4	5	3	2	4
37923.3800	925.0467	51	50	3	2	5	2	5
943715.8000	11288.7900	55	54	2	4	6	1	1

NOTES :

Slopeco - Code of Slope Class
1-Class A; 2-Class B; 3-Class C; 4-Class D; 5-Class E; 6-Class F; 7-Class G
Rocksco - Code of Rock type
2 - Loess; 3 - Interbedded Sand; 4 - Alluvium-Colluvium; 5 - Int.Limestone-sand
Soico - Code of Soil Type
1- Dannevirke S L; 2- Dannevirke S L Roll Phase; 3- Wheturkura S I
4- Wheturkura Hill Soils; 5- Kiwitea Pa Sd Lm Roll Phase; 6- Utuwai S L.
Proneros- Code of Potential Erosion
1 - None; 2 - Slight; 3 - Moderate; 4 - High
Comb - Code of combination of these factors

Step IV: Dissolving the multi-factor map

AREA	PERIMETER	POTEROS_	POTEROS_ID	PRONEROS	COMB
85743.8100	2320.6220	116	115	1	1
1068666.0000	6684.5300	2	1	1	2
101353.8000	3173.6470	15	14	2	3
144581.3000	1884.2800	102	101	2	4
36528.0000	1177.8210	104	103	2	5
64936.4400	1315.1200	31	30	3	6
38232.9400	1285.8290	107	106	3	7
81280.2500	1622.6450	30	29	4	8
145839.8000	1914.6450	85	84	4	9

Figure 11 : Database analysis procedure for potential erosion assessment

combinations of factors which led to the classification. These combinations were subsequently used to identify conservation needs for each land unit.

Table 7 : Criteria which were used to assess potential erosion

Potential erosion	Slope angle	Rock type	Soil type	Combination
Not susceptible	A, B	Alluvium/colluvium	Ut	1
		Loess and tephra	D	2
Slight	C, D	Interbedded sand-siltstones	Wt	3
		Interbedded lime-sandstones	Wt	4
		Loess and tephra	DR, KwR	5
Moderate	E	Interbedded sand-siltstones	WtH	6
		Interbedded lime-sandstones	WtH	7
High	F, G	Interbedded sand-siltstones	WtH	8
		Interbedded lime-sandstones	WtH	9

Notes:

Slope classes:

A = 1 - 3 degrees
B = 4 - 7 degrees
C = 8 - 15 degrees
D = 16 - 20 degrees
E = 21 - 25 degrees
F = 26 - 35 degrees
G > 35 degrees

Soil type:

D = Dannevirke silt loam
DR = Dannevirke silt loam, rolling phase.
KwR = Kiwitea fine sandy loam, rolling phase
Ut = Utuwai silt loam
Wt = Whetukura silt loam
WtH = Whetukura hill soils

Defining Conservation Needs

As discussed previously, defining the conservation needs of the study area depended on the combination of factors that were used to assess potential erosion. Areas with the same potential erosion ranking may be susceptible to different erosion types and therefore need different conservation practices. This is because the same degree of potential erosion might be derived from different combinations of factors.

Table 7 indicates there are nine possible combinations to give the four degrees of potential erosion. Each combination is described below.

Combination 1

Map units include deposition areas and those on flat ground, with recent soils and are usually near streams or watercourses. The soil is weakly developed and subject to flooding. Open channel drainage is recommended to both lower the water table and rapidly remove any surface flooding. In deposition areas, conservation tillage is required to improve soil structure. In lower areas near streams, tree planting is also recommended for streambank protection.

Combination 2

These map units also occur on flat areas, but are not subject to flooding. The soil type is Dannevirke silt loam, a soil developed from loess. Silt is dominant in the A and B horizons, hence subsurface drainage and wind breaks are recommended. Loess is considered to be more wind erodible than in combination 1.

Combination 3

This includes map units which have a slight erosion potential. They have slope classes C and D and soils are Whetukura silt loams developed from interbedded sandstone-siltstone. Spaced tree planting on colluvial footslopes will minimize the potential for flow erosion. Strip cropping is recommended for those areas on C slopes that will be cultivated.

Combination 4

These map units are derived from the same slope class and soil type as combination 3 but the soil was developed from interbedded limestone-sandstone. Soils are shallow with a fragipan in the B horizon. Graded banks (diversion ditches) on a gradient of 1 : 100 - 1 : 80 across the hill sides are recommended to remove excess water to safe disposal areas.

Combination 5

This combination has the same potential erosion and slope angle as combinations 3 and 4 but has Dannevirke silt loam rolling phase and Kiwitea fine sandy loam rolling phase soils developed from loess. Some areas of Kiwitea fine sandy loam rolling phase have slight drainage problems due to an impermeable sub soil layer. Top soil is silty with a poor structure. Conservation tillage and contour cultivation are recommended for C slopes. D slopes need to be space planted with

Poplar (*Populus* spp) or Willows (*Salix* spp). Wind breaks may also be necessary to guard against a slight wind erosion potential when cultivated.

Combination 6

This combination occurs on steep slopes (class E) with Whetukura hill soils derived from interbedded sandstone-siltstone. As these areas have a moderate potential erosion, they require more intensive conservation practices to minimise the risk. Production woodlots are recommended for these areas.

Combination 7

This combination has the same degree of susceptibility to erosion as combination 6. The soil type is Whetukura silt loam, derived from interbedded limestone-sandstone. These areas are less suited for tree planting because they have a shallow soil with a fragipan in the B horizon. Based on this condition, grazing to ensure a complete and healthy ground cover is the recommended land use. Open planting of Poplar (*Populus* spp) along ephemeral drainage lines is also recommended.

Combination 8

This combination occurs in unstable areas which have Whetukura hill soils that were developed from interbedded sandstone-siltstone. A poor topsoil structure and steep slopes means these areas are very prone to landslide erosion. Hence tree planting is required. Production or erosion control forestry is recommended.

Combination 9

These areas are those which have Whetukura hill soils and a high susceptibility to erosion because of very steep slopes and a fragipan layer which can activate a slip surface. The shallowness of the topsoil restricts tree planting. Consequently complete ground cover with restricted grazing is recommended.

Results and Discussion

Results of the Assessment

The potential erosion map produced from this analysis is illustrated in Figure 12 and the conservation needs map based on the potential erosion in Figure 13. The area of each combination is shown in Table 8.

In contrast to the dissolving process described in Chapter IV (Table 5), which resulted in a generalization of the combinations, the dissolving process in this step did not replace any combinations. The different number of polygons before and after the dissolving process in this operation was not caused by joining polygons having different combinations leading to the same potential erosion. Instead, it was caused by joining polygons with the same rock type and soil type but different slopes.

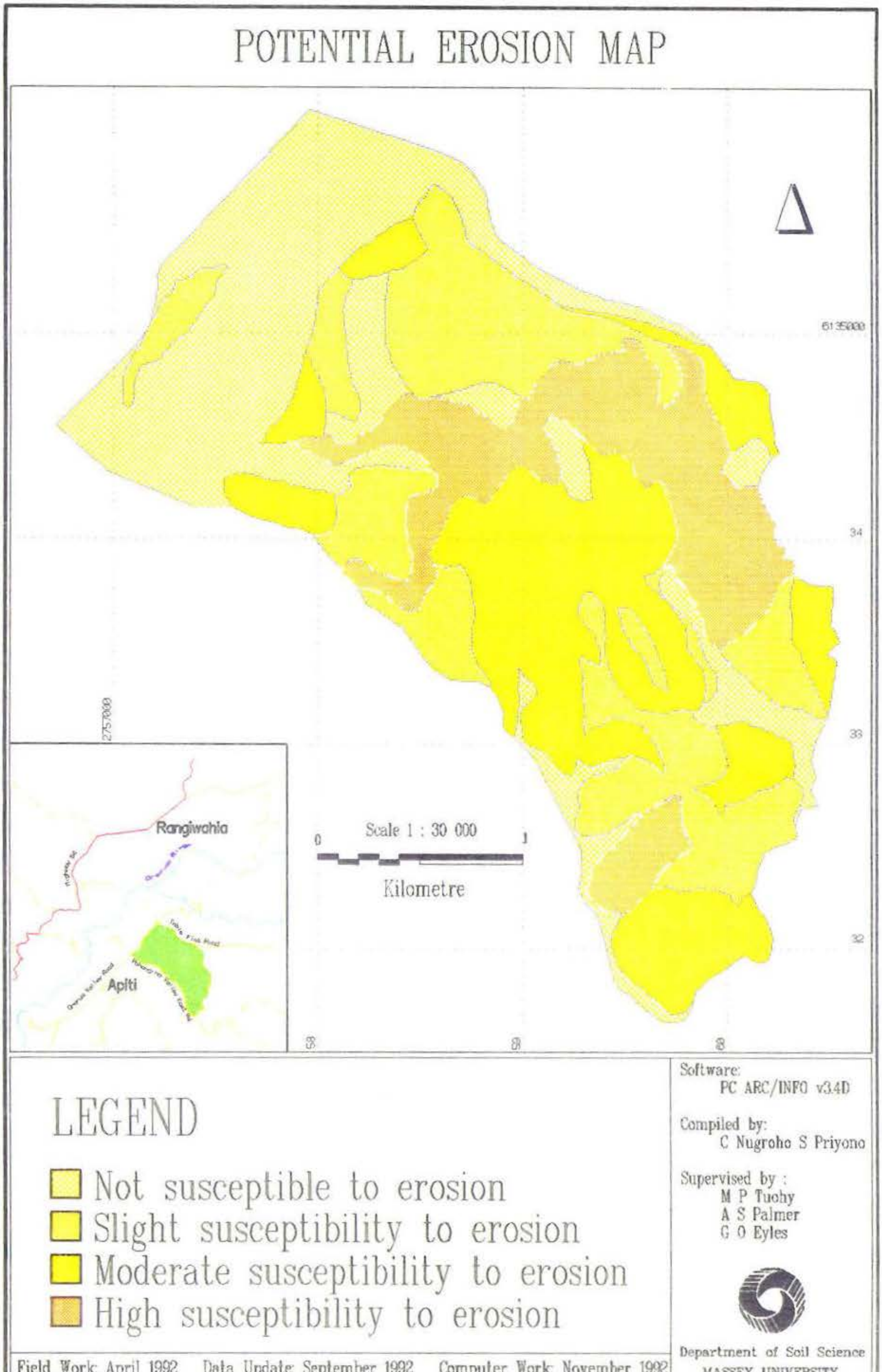


Figure 12 : Potential erosion map

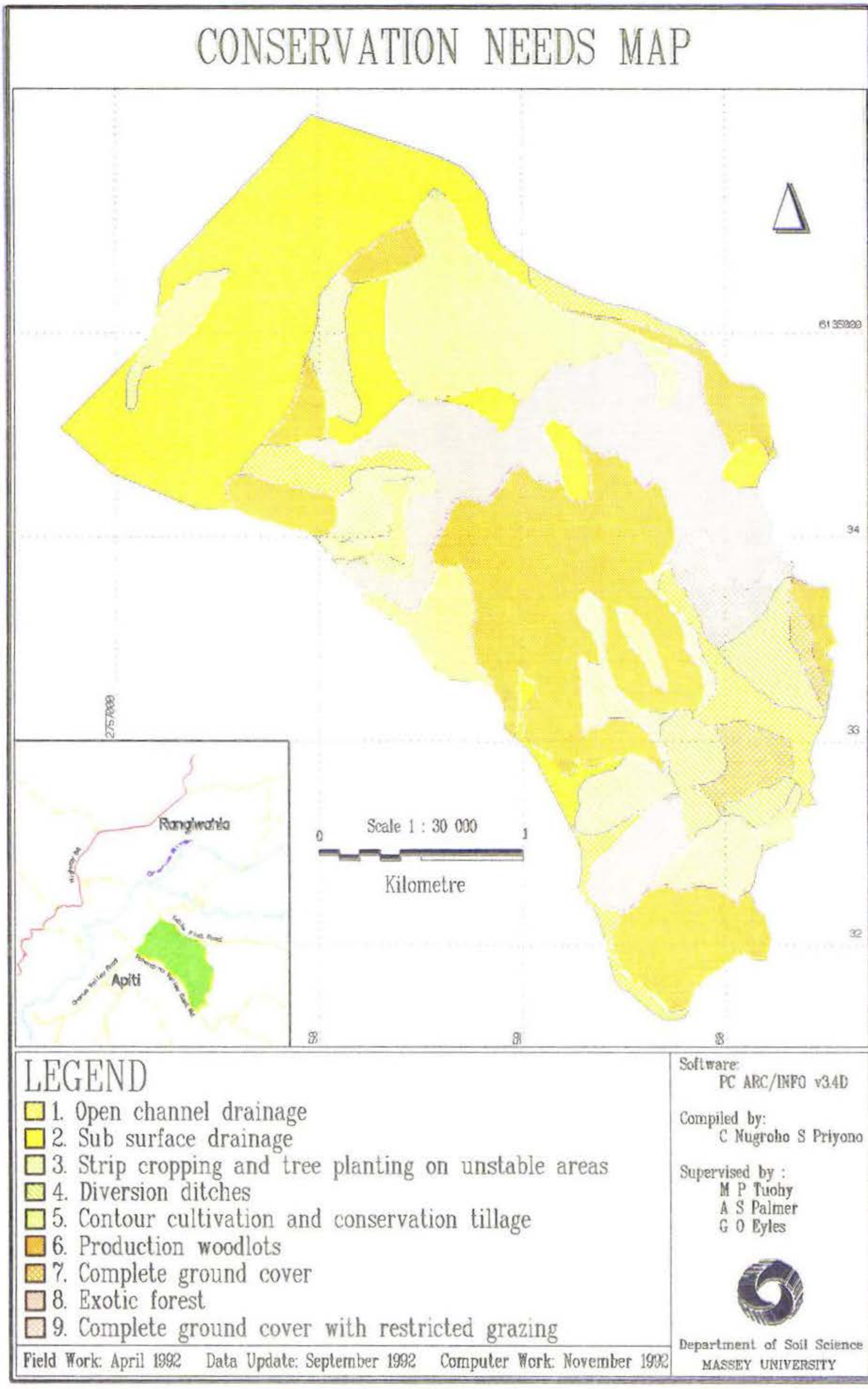


Figure 13 : Conservation needs map

Table 8 : Total area of each combination and potential erosion grade.

Combination	Potential Erosion	Number of Polygons Before Dissolving	Number of Polygons After Dissolving	Total Area (Ha) Before Eliminating	Total Area (Ha) After Eliminating
1	Not susceptible	6	4	44	43
2	,,	11	6	189	189
3	Slight	11	6	66	66
4	,,	4	3	31	31
5	,,	12	6	101	101
6	Moderate	13	7	194	194
7	,,	2	2	15	15
8	High	5	2	120	121
9	,,	1	1	15	15
Total		65	37	775	775

The eliminating process, on the other hand, caused generalization on this map and this can be identified from the difference in total area before and after the eliminating process. The minimum area of polygons which could be eliminated in this process was decided on the basis of the scale of analysis. At the scale of 1 : 20 000, the minimum area of polygons that can be clearly shown in a map is approximately 0.5 cm^2 (1 ha on the ground). Hence, the eliminating process in this step, as well as in the previous step, eliminated polygons having an area less than 10 000 m^2

Discussion

Potential erosion assessment should be distinguished from the severity of erosion assessment in the previous chapter. Erosion severity is an objective assessment of what exists in the field. Potential erosion assessment, on the other hand, was based on the combination of various factors. There may be no evidence of erosion in the field although the area is categorized as moderately susceptible to erosion. This may be because the area is being managed sustainably or high intensity or prolonged rainfall has not affected the area for some times. However, such an area is included in the moderate ranking as the land is physically moderately susceptible to landslide erosion.

Some adjustment was made during field observations to the criteria that were used to assess potential erosion. Thus, field observation is important not only to confirm the feasibility of the criteria but also to make adjustments wherever necessary. For example some soils which usually occurred in steeper areas were found on colluvial footslopes as they have been deposited there as landslide debris. These soils usually have the same characteristics as those on steeper slope areas above the colluvial area. Although the potential erosion of these areas was assessed as grade I (not susceptible to erosion), the soil type in these areas was the same as soils in the areas with steep slopes.

From field observations, it was also found that rock type and soil hydrologic properties played important roles in determining land stability. Initially, the rock type of the study area was predicted to be dominated by interbedded sandstone-siltstone and loess as found in the Table Flat area. Loess mantled interbedded sandstone-siltstone. The interbedded sandstone-siltstone, in particular, contains loose material and beds gradually become more compacted with depth. As a result, the deepest bed was usually impermeable. Impermeable beds underneath loose materials on steep slopes may initiate a mass movement. This hypothesis was used as one of the basic assumptions in selecting the criteria (Table 7) for potential erosion assessment.

As described in Chapter II a large landslide is thought to have occured in the study area and this comprises the major landform. It is thought the slip surface of this event might have become a subsurface flow zone. This is suggested by the frequency of springs in the footslope areas. In high rainfall events, the subsurface flow off the Table Flat scarp slope and on the colluvium of the hills where springs occur can initiate soil slips. This phenomenon was observed after a heavy rainfall on August 1992 in which some soil slips occurred in areas with springs in footslope areas. This event also provided an opportunity to examine the accuracy of criteria used for potential erosion assessment. Of the eight soil slips which occured five were in areas classified as having a high susceptibility to erosion and the remaining three were in areas classified as having a moderate erosion potential.

Despite some adjustments in the field observations, the map generalization was also carried out in the resulting map. Using GIS in general and PC ARC/INFO in particular, some kinds of map generalization can be automatically done. Some PC ARC/INFO commands such as ELIMINATE and DISSOLVE can be used to carry out the map generalization. However the map generalization has to be propagated at every step of the analysis to show validation and sensitivity of the analyses. Table 8, as well as Table 5 in Chapter IV, show the significance of map generalization.

CHAPTER VI

FARM SOIL CONSERVATION PLANNING

Introduction

Farm soil conservation planning in this study was carried out using information detailed in previous chapters. The process involved matching information by overlying polygons representing land units which have specific characteristics. As soil conservation practices are integral parts of management, recommendations for land management activities were then given for each land unit based on information in the database. From the information and recommendations, management options were provided for the farmers so that they might make informed choices.

The use of the GIS played an important role in combining information to provide the management options for land holders. The GIS also enabled the definition of other factors important for management purposes such as paddock areas and length of fence lines. Although farm soil conservation planning could be carried out by exploring the information and manipulating the database, it had to be based on farmer requirements. The farmer's aspirations had to be considered in the planning. Hence, it was important to involve the farmers at all stages of planning.

Basic Principles of Farm Soil Conservation Planning

The first step in soil conservation planning is to identify the causes of land degradation. Since degradation usually results from incorrect land use and management, it is necessary to know why undesirable land uses are being practised. In the study area the main constraints to improving production were compacted subsoil layers in the flat areas and soil slip in the hills.

If the conservation planning is to be effective, every effort must be made to develop practices that not only conserve the soil but are also able to provide tangible benefits to the farmers. This may mean introducing strategies that will lead to conservation practices which increase yields, reduce risks or provide other benefits, while at the same time preventing or controlling erosion. Thus soil conservation practices should be integrated with land management and land husbandry practices.

The concept of achieving soil conservation through good land husbandry has been discussed by many authors such as Shaxson *et al* (1989); Sanders (1990 and 1992) and Hudson (1992). They contend that soil conservation should be an integral part of agriculture. Strategies must pay more attention to soil management practices. Considering the main problems of the study area, management practices should be proposed to increase soil organic matter content, prevent the formation of soil crusts and compacted layers, and generally improve soil structure and water holding capacity. In practice, this involves utilising crop residues, introducing better crop rotations, improving pasture management and other agronomic measures. As well as these measures, design and planning of sustainable land uses may include physical erosion control earthworks such as drains and channels. But if emphasis was first placed on making maximum use of water where it falls, the need for physical conservation works could be greatly reduced. Thus, the primary thrust should be better soil management, with earthworks used only when they are unavoidable.

Above all, farmer cooperation and participation is very important to the success of such planning. The land users have to be involved at every stage of the plan so that they might become more aware of the benefits. Thus attention should be focused on helping farmers to improve their management of the land. In this study, the farmers were involved right from the initial stages when the land resource inventory was prepared. Land holders were involved in discussion and gave much information related to their land management problems. Their requirements were also considered when producing the interpretative maps.

Three basic approaches which have to be considered in farm soil conservation planning (Shaxson *et al* 1989) are:

a. The soil conservation practices should enable increased plant production from land without provoking soil destruction.

b. The plan should integrate conservation into agriculture practices.

c. The plan should harmonize the view of landholders and conservators or planners.

In addition, it should be realized that soil conservation cannot work miracles by instantly returning degraded land to a state of full and sustainable productivity. Physical works cannot make up for the effect of poor land use and management.

Hence, the most important way to express these three basic approaches to achieving conservation of soil and water values is to ensure that the use and management of the land in any particular area is appropriate to the physical characteristics of that land.

Different forms of land use vary in their capacity to protect the land resource. It is not sufficient to classify the many different types of agricultural use into broad types such as annual crops, pasture or forest. This is because various land management options can have significant effects on the land's capacity for production and on its susceptibility to erosion. For example, poorly managed pasture on a steep slope with compacted soils and little vegetative cover may be a less productive and less protective use than a well-managed silvo pastoral system maintaining excellent cover and structural condition on the same slope. Thus management of each land use is very important despite the capability of the land.

Appropriate land use options, based on land characteristics, were determined in the land use capability classification, and soil conservation needs based on the potential erosion hazard were defined in the previous chapter. There were two outcomes from these procedures: a potential land use map and a conservation needs map. The LUC classification map provided information on land use options to farmers. If this map was overlaid by the conservation needs map, the farmers would be able to obtain more detailed information. Land units on individual properties might become smaller and more specific. Areas that were suitable for cropping (Classes I - IV), for instance, could be described in more detail as to which parts of the area needed more intensive soil conservation practices or more careful management. Even those areas that had the same suitability for a particular use, might need a different management input to achieve sustainable production.

Using the GIS, a procedure could be developed for selecting further management practices such as identifying sites for additional stock-water ponds, or deciding on the rotation for pasture management. Operations to select pond sites might be further enhanced by using a Digital Elevation Model (DEM). Rotation schemes for pasture management could be designed using area information from the attribute table of the paddock coverage. Perhaps some paddocks might need to be subdivided for more efficient pasture management. Recommendations for fencing operations may also be decided by considering the various overlays. Additional detailed information such as the length of fences, could be easily obtained from the arc attribute table.

In conclusion, this step explored information from the database and combined it in such way as to define recommendations for farm management practices in general, and farm soil conservation planning in particular.

Recommendations for Management Practices

General Recommendations for Land Management Practices

As erosion is not an universal problem, soil conservation should be targeted to areas at risk and the management should consider factors affecting erosion. However, before recommendations were given for each land unit, the general principles to be followed in the study area are described below.

In parts of the world, the most important engineering work for controlling erosion on agricultural land is terracing. As terracing is most appropriate where runoff rates are high or where steep slopes need to be cultivated (Hudson, 1992), terracing is unlikely to be applied in the study area. Controlling surface runoff, however, can be carried out using open drains. Observations on clay soils have suggested that underdrainage can reduce surface runoff volumes significantly (Armstrong *et al*, 1990). Consequently, drainage can be undertaken as a technique for the control of erosion by surface runoff. Therefore, a drainage system was recommended for most of the flat land in the study area.

Cross-slope interceptors also provide a positive approach, either by encouraging infiltration or by diverting surface runoff to a controllable discharge structure. Such interceptors, also known as diversion banks, offer considerable potential for breaking up flows before they become erosive. In effect, they reduce the slope length by breaking it into a series of shorter sections. Such practices were recommended for long slope areas of the study areas.

Cultivation practices can also be applied to reduce the erosion risk. There are two cultivation practices recommended for the study area, based on local conditions: contour cultivation and conservation tillage.

- Contour cultivation means soil cultivation along contours. The current practice in the study area of performing field operations up and down slope, was adopted for personal comfort, safety on steeper slopes, and mechanical efficiency. But such practices encourage both surface runoff and soil slips because these practices enable flows to become concentrated in rills, which increase the velocity and erosiveness. Thus, cross-slope cultivation was recommended in some parts of the study area.

- Conservation tillage, on the other hand, is defined as a tillage system that reduces loss of soil or water relative to conventional tillage; often a form of non-inversion tillage that retains protective amounts of residual mulch on the surface (Mannering and Fenster, 1983). Conservation tillage reduces soil and water losses by leaving appreciable crop residue on the soil surface and/or leaving the surface rough, porous, cloddy or ridged. Conservation tillage was recommended in many parts of study area.

The minimizing of soil compaction and the encouragement of infiltration can be achieved by avoiding overcultivation and overcompaction, and the incorporation of crop residues. Rotations of cropping and pasture can also improve soil structure improving infiltration.

A permanent vegetation cover such as exotic forest, or spaced tree planting was considered valuable for land stabilization and to protect against surface soil detachment. Spaced tree planting could be applied on colluvial footslope areas which had drainage problems as well as those areas prone to soil slip. The trees could be expected to increase the rate of soil drying through transpiration, which would help to reduce the incidence of soil saturation and hence improve internal drainage and reduce runoff generation.

Application of the above erosion control measures would be integrated with recommendations for specific land management practices. These are discussed in the next section

Recommendations for Each Land Unit

As recommendations for each land unit would be given on the basis of previous interpretations, all the information was put in a database. Combinations that occurred in the database were grouped into twelve land units according to established criteria (Table 9). Each land unit had information about potential land uses, limitations, potential erosion and conservation needs. Recommendations were then given for each land unit by considering this information. The resultant map identified where the different management activities should be carried out (Figure 14). An extended legend for this map is described in the following pages.

Land unit 1 (yellow)

This land unit occurred in three separate parcels with a total area of 25 ha. They were all flat areas with Dannevirke silt loam soils developed from loess. This unit has a high potential for cropping with either no or a very slight potential for erosion, mainly wind erosion caused by westerly winds. Thus, wind breaks especially along the corner of Oroua Valley Road and Pohangina Valley East

Table 9: Criteria defining land management recommendations

Land Unit	LUC Class Subclass	Potential Erosion	Code of Cons.needs	Recommendations for management practices
1	I w II c	1 1	2 2	High potential for cropping Needs windbreaks and sub surface drainage
2	III w	1	1, 2	Moderate potential for cropping, needs drainage, contour cultivation, conservation tillage or strip cropping. Spaced tree planting on unstable areas.
3	III c IV c	2	3, 5	Moderate to low potential for cropping, needs more intensive conservation practices of conservation tillage and contour cultivation.
4.	IV e	2	3, 5	Low potential for cropping, needs very intensive conservation practices of conservation tillage, contour cultivation, strip cropping and spaced tree planting.
5	V w	2	3, 4, 5	High potential for pasture, needs drainage, spaced tree plantings on footslopes to stabilize the land.
6	V s	2	3, 4, 5	High potential for pasture, needs conservation tillage for pasture renewal to build soil structure.
7	V c	1, 2	2, 5	High potential for pasture, needs windbreaks and contour cultivation when preparing for a seedbed.
8	VI e	3, 4	6, 8	Recommended for agroforestry, restricted grazing before agroforestry established.
9	VI w	3	6	Recommended for agroforestry, open channel drainage is necessary to improve pasture.
10	VI s	2, 3	3, 7	Shallowness restricts permanent vegetation. Recommended for extensive grazing with complete ground cover.
11	VII e	4	8	Areas having high potential erosion, recommended for exotic forest (*Pinus radiata*), pasture with restricted grazing can be used during forest establishment.
12	VII e	4	9	Shallowness restricts range of trees, diversion ditches necessary. Pasture with very restricted extensive grazing can be used in these areas.

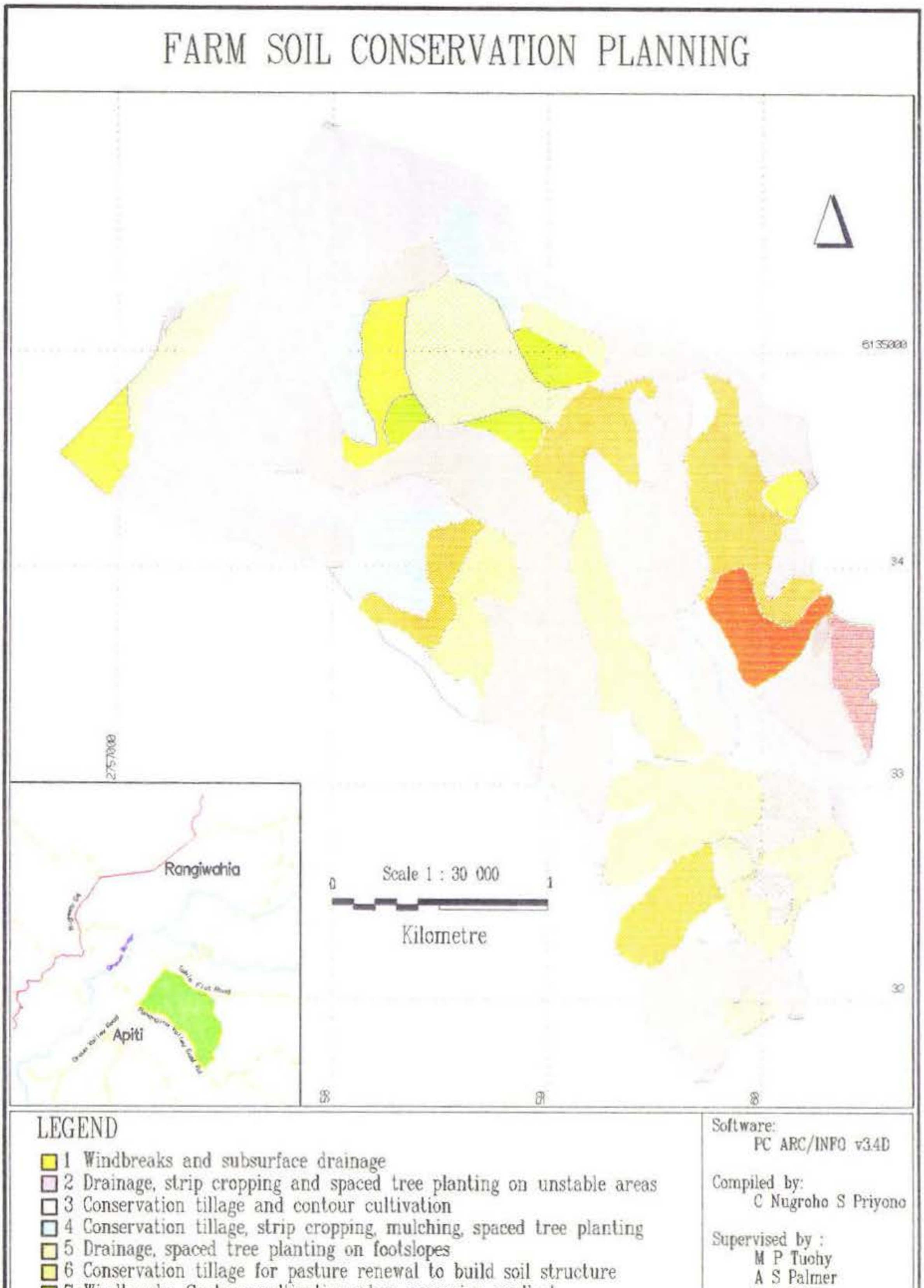


Figure 14 : Farm soil conservation planning

Road, might be necessary (see Figure 2).

Land unit 2 (pink)

This land unit was the second largest in the study area with a total area of 202 ha. Soils include the Dannevirke silt loam and the Utuwai silt loam. It has a moderately high potential for arable use primarily with drainage limitations on the latter soil. The poor drainage occurs because these areas are on the colluvial toeslopes or colluvial fans with water from adjacent hills flowing across them. Consequently, a drainage network might be necessary for these areas with waterways being used as outlets. These areas have also had a soil compaction problem due to incorrect cultivation when the areas were used for cropping. They are currently being used for pasture grazing by sheep and cattle. If the areas were intended for cropping, conservation tillage should be practised to avoid soil compaction. Spaced tree planting on colluvial fan areas could improve drainage and stabilize the land.

Land unit 3 (blue)

This unit has only a moderate potential for cropping, and covers 16 ha, mainly in small valley floors surrounded by hilly areas. The major limitation is climate because of the elevation. Currently, these areas are sometimes used for winter feed crops. They will need contour cultivation and conservation tillage if they are to be cropped more intensively.

Land unit 4 (dark blue)

This unit includes areas having a low potential for cropping because of the high erosion hazard. If these are to be used for cropping, they will need very intense conservation practices. As with unit 3, conservation tillage and contour cultivation should be practised. Spaced tree planting should also be carried out in colluvial fan areas. In the future, these trees might also be windbreaks for those areas in western parts of the study area prone to wind erosion. This land unit occupies a total area of 40 Ha.

Land unit 5 (coarse texture green)

This land unit is not suitable for arable use because of drainage problems. It occurs throughout the study site and has a total area of 51 ha. To improve pasture it needs either subsurface or open channel drainage. On colluvial footslope areas, it needs spaced tree planting to not only stabilize the land but also to improve drainage conditions.

Land unit 6 (green)

The 90 ha mapped in this unit are not suitable for cropping because of either shallowness of the soil or steepness of slopes. However this land has a high potential for pasture growth. Although some areas have steep slopes other areas are less steep and very stable, and pasture renewal is possible with conservation tillage. In relatively flat areas, soils are shallow and structureless and so conservation tillage could be used to build soil structure.

Land unit 7 (dark green).

This occurs in the highest parts of the study area and covers 14 ha. The Dannevirke silt loam rolling phase is moderately deep with a well developed structure in the top soil. These areas are not suitable for arable use because of the high altitude that results in a decreased growing period for crops. However, they have a high potential for pastoral use. This land unit has a slight potential for erosion, particularly wind erosion due to the high proportion of silt in the surface soil. Consequently wind breaks are recommended.

Land Unit 8 (red)

This land unit has a moderate to high potential for erosion, however it also has a moderate potential for pasture production. In the field, it could be easily recognized by the existing good pasture sward but moderately severe slip erosion. The vulnerability to erosion is caused by the loose layered interbedded sandstone-siltstone on the steep slopes. The most urgent need for this unit is to prevent slip erosion, consequently agroforestry is recommended. Under a farm forestry system the land may be stabilized, while at the same time, pasture under the trees can be utilized. However, due to the high vulnerability to erosion grazing needs to be restricted while the trees become established. This land unit was the largest in the study area with total area of 213 ha (26%).

Land unit 9 (dark red)

This was the smallest land unit in the study area, occurring only in one area of 10 ha on the eastern margin. It has a moderately low potential for pasture production because of serious drainage problems. The summer water table was approximately 20 cm below the surface, and higher in the winter. Open channel drainage might solve the problem and agroforestry could follow after the drainage problem has been solved.

Land unit 10 (coarse texture red)

This land unit is not suitable for arable use because of the shallowness of the soil. It has Whetukura silt loam soil developed from interbedded limestone-sandstone. Potential erosion is moderate because of a fragipan underneath the topsoil. This shallowness restricts the growth of trees and consequently grazing, while maintaining complete ground cover, is the best option for these areas. This land unit occupies a total area of only 19 ha.

Land unit 11 (brown)

With steep slopes and some soil slips this unit of 79 ha is easily distinguished. It has a low potential for pasture production and a high susceptibility to erosion. The most suitable use is permanent vegetation e.g exotic forest. *Pinus radiata* is the recommended species. However, restricted grazing, may also be utilized during forest establishment.

Land unit 12 (dark brown)

This unit occupies only 14 ha and has a high potential for erosion and a low potential for pastoral use. Shallow soils restrict its potential for trees so maintaining the pasture sward with restricted grazing is the best practise. Diversion ditches in the shoulder slope might also help to prevent soil slip.

Additional Improvements

Grazing Management and Paddock Maintenance

Since dominant land use in the study area is pastoral additional management improvements discussed in this section relate to grazing management and paddock maintenance.

According to Murphy (1990) there are two basic methods of grazing management: continuous, often called set stocking, and rotational, which has many names. Continuous grazing involves trying to match a set number of livestock with pasture grown within the same area during the entire grazing season. As a result, continuously grazed pasture tends to be overgrazed in some seasons due to seasonal variations in plant growth. Rotational grazing, on the other hand, controls what and when livestock eat, by dividing pasture into small paddocks and rotating animals through them. In the study area, rotational grazing was the most popular system although it has the disadvantage of focusing trampling damage on a small paddock in adverse weather or ground conditions.

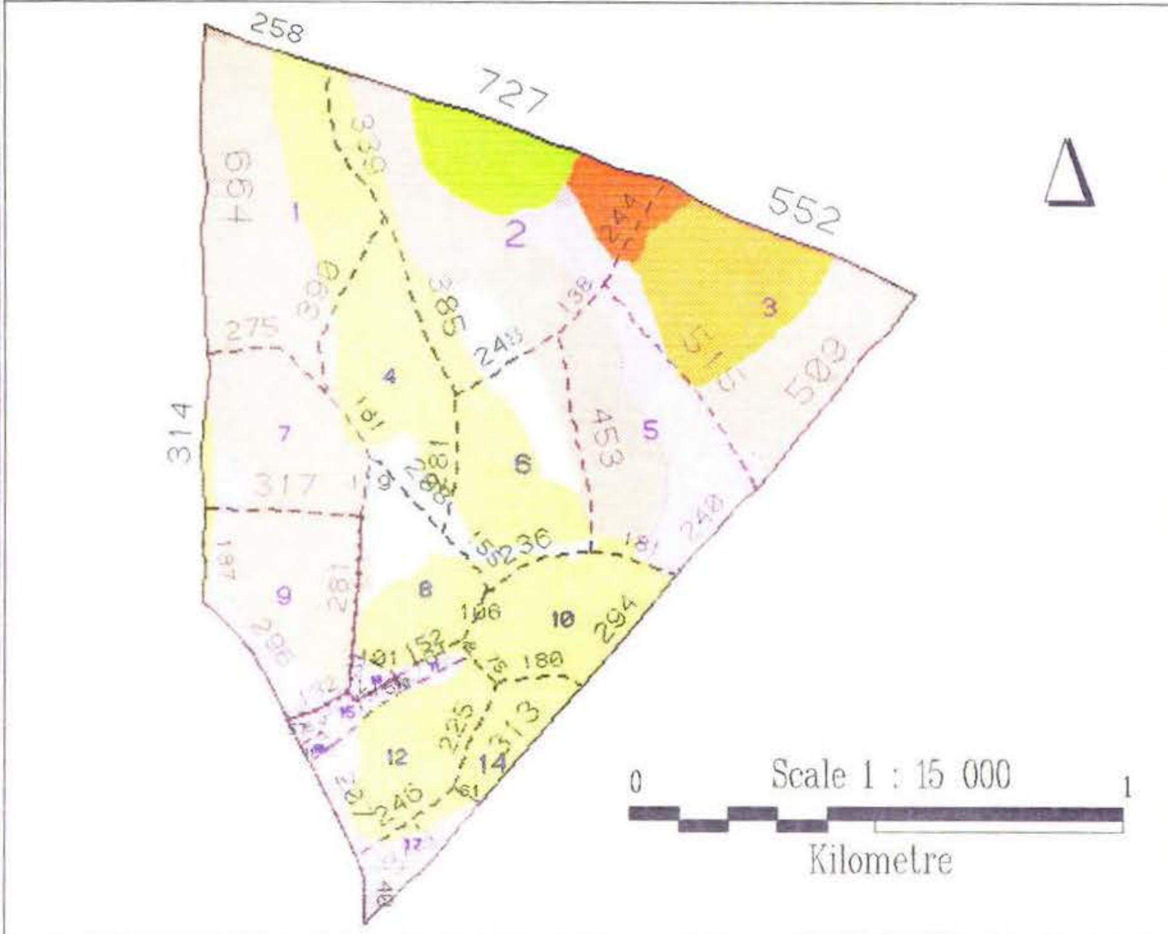
As a rotational system concerns resting paddocks between grazing periods, paddock areas are very important. Paddocks must be small enough so that all forage in each paddock is uniformly grazed within each occupation period. In short, for effective grazing management, significant information is needed: paddock area, pasture species and carrying capacity of each paddock.

The GIS is able to provide this information for improving grazing management. The paddock area can be obtained from standard items which are always contained in a polygon attribute table.

In addition, information about pasture species was collected in the LRI so that it could be easily displayed. Generally, there were two dominant pasture species in the study area: Browntop (*Agrostis tenuis*) and Ryegrass (*Lolium sp*) in association with white clover (*Trifolium repens*). In some parts, particularly those which have drainage problems, Rushes (*Juncus sp*) were common.

The carrying capacity of a paddock refers to the definition by Budd (1992) that can be simplified as "the number of livestock that can be supported in a given area without the degradation of the land". The carrying capacity of each paddock might be approximated using other information in the database such as paddock area and slope angle. When fence replacement is needed to adjust the carrying capacity, the GIS can supply data on the kind and length of fence required. Management recommendations for each paddock can be obtained by overlaying the recommendations map with the paddock map. An example of displaying selective information from the database for a particular property is shown in Figure 15.

LAND INFORMATION MAP ON PROPERTY BASIS



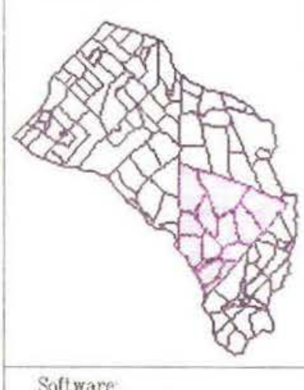
LEGEND

- Fence
- Electric fence
- Property boundary

230 Length of fence (m)
8 Paddock number

RECOMMENDATIONS FOR MANAGEMENT PRACTICES

- Drainage, strip cropping, spaced tree planting on unstable areas
- Conservation tillage and contour cultivation
- Conservation tillage for pasture renewal to build soil structure
- Drainage, spaced tree planting on footslopes
- Agroforestry, restricting grazing before trees are established
- Agroforestry, with open channel drainage
- Exotic forest, restricting grazing during forest establishment
- Pasture with very restricted grazing



LAND INFORMATION

PADDOCK NUMBER	HA	VEGETATION	LUC CLASS SUBCLASS	SOIL TYPE	SLOPE
1	17.9	Browntop	Vs/VIe	D/Wt/WtH	E
2	22.8	Ryegrass	IIIw/Vw/VIe/VIIs	D/Wt/WtH	B/C/E
3	18.8	Ryegrass, rushes	VIe/VIIs	Wt	D/E
4	9.5	Ryegrass	IIIw/Vs	Wt/WtH	C/E
5	13.3	Ryegrass	IIIw/VIe	Wt/WtH/Ut	B/E
6	10.4	Ryegrass	IVc/Vs	D/WtH	C/E
7	9.1	Ryegrass	IIIw/VIe	D/WtH	B/E
8	7.3	Browntop	IIIw/Vs	Wt/WtH	B/C/E
9	10.1	Browntop	IIIw/VIe	D/WtH	B/E
10	7.6	Ryegrass	Vs	Wt/WtH	D/E
11	0.5	Ryegrass	IIIw	Wt	B
12	7.6	Ryegrass, rushes	IIIw/Vs	KwR/Wt	B
13	0.5	Ryegrass	IIIw	Wt	B
14	3.0	Browntop, rushes	Vs	WtH	B/D
15	1.2	Ryegrass, rushes	IIIw	Wt	D
16	0.2	Browntop	IIIw	Wt	B
17	2.5	Browntop	IIIw	KwR	B/D

Software:
PC ARC/INFO v3.4D

Compiled by:
C Nugroho S Priyono

Supervised by :
M P Tuohy
A S Palmer
G O Eyles

Department of Soil Science
MASSEY UNIVERSITY

Figure 15 : Land information map on property basis

Additional Dam Sites

Farm dams are proposed not only to provide water for livestock but also as erosion control measures to catch sediment resulting from erosion in the catchment and as fire fighting reservoirs if forestry is established. Some existing dams are scattered in the study area. However, the GIS would be able to provide information for the position of additional dams if required.

Operations to select areas suitable for dam sites were carried out by map analysis using three maps: elevation, rock type, streams. The elevation map was used to select areas which have elevation above 500 m from where water could be reticulated by a gravity system to troughs on other parts of the farm via alkathene pipes. Streams in these areas were assumed to have only small catchments. The rock type map was used to indicate sites with alluvium, colluvium or loess as these materials are more suitable for earth dam construction than harder rocks. The width of the dam was arbitrarily restricted to not more than 50 m, so the stream map was simply buffered to show the area occupied by 25 m strips on either side of the streams.

Using PC OVERLAY's INTERSECT command areas which met all these criteria were selected. Definitive sites were identified by viewing the stream coverage, after it had been draped onto a three-dimensional representation of the study area. This permitted the selection of sites which occupy narrow valleys and are topographically suitable for dams. The result of these operations is shown in Figure 16.

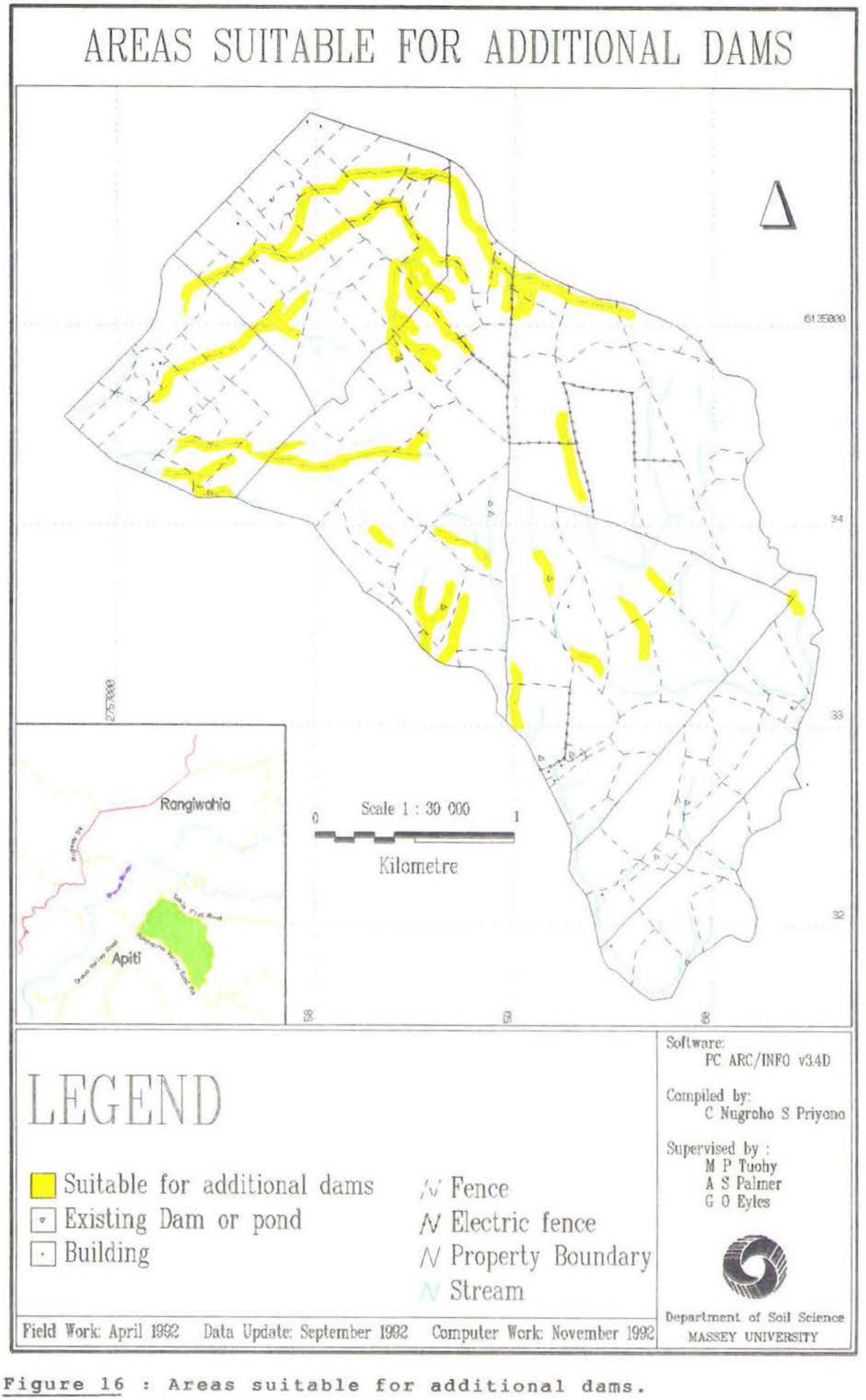


Figure 16 : Areas suitable for additional dams.

Discussion

The main problems in the study area were soil compaction in the areas of low relief and a high potential for erosion in hilly areas due to uncompacted rock material on steep slopes. These problems significantly reduce agricultural production. Thus, land use recommendations should attempt to solve soil physical problems and provide a better medium for plant growth.

Soil physical characteristics, water, oxygen, temperature and mechanical resistance impairing seedling emergence or root growth all directly affect plant growth. Bulk density, texture, aggregate and pore size distribution all indirectly affect plant growth because of their effect on soil water, aeration, temperature and mechanical resistance (Letey, 1985). In terms of water, the most important factor is not soil water content but soil water potential that refers to the energy with which water is retained in the soil and consequently the energy necessary for water to be removed from the soil by plant roots. Also, plant roots respire, consuming oxygen and producing carbon dioxide. Heat is needed for metabolic processes. Hence, it can be concluded that improving soil physical characteristics for better plant growth should be achieved by optimising these factors so that the most favourable environment for the plant is established.

Accordingly, what is the optimum value for each of these factors ? It is not possible to determine the optimum value because this is dependent upon many variables such as: species of plant, stage of plant growth and climate. Management practices, however, manipulate soil characteristics to provide improved conditions which result in better plant growth and thus increase production.

As land management practices manipulate soil characteristics, they may be proposed for soil conservation purposes so that conservation efforts can be integrated with land management for a particular farming system. In the study area, conservation efforts concentrated on improving soil physical properties for better plant growth and for reducing erosion. To achieve these purposes, land management practices aim to increase organic matter content. This is because the organic matter content affects soil aggregation, bulk density, moisture retention and water movement.

The relationship between organic matter and soil aggregation was discussed in detail by MacRae and Mehuys (1985). They mentioned that organic matter plays only a minimal role in aggregate formation, but it plays a primary role in aggregate stabilization. The decomposition products of plant and animal residues are responsible for aggregate stabilization. As interbedded sandstone-siltstone is the dominant rock type in the study area, increasing organic matter content can be expected to improve soil aggregation, particularly areas with shallow soil.

The improvement of soil aggregates will directly improve bulk density and thus reduce soil compaction. Also, organic matter content is highly correlated with infiltration and it may increase available water. Again, it clearly shows that the increasing organic matter can be expected to solve the main problem in the study area. Based on these facts, conservation tillage, which primarily aims to cultivate the land and increase organic matter content by retaining plant residues, was recommended for most areas.

When making recommendations for management practices, it was important to build recommendations on what farmers know rather that expecting farmers to adopt new systems. Field experience shows that farmers may welcome and adopt improvements to these known and familiar practices, already integrated into present farming systems, much more readily than they will adopt alien recommendations that they feel do not fit their needs. Because of this reason, most recommendations given in this study were familiar practices about which farmers already know.

Even though recommendations were provided, it should be noted that farmers may not want to practice the recommendations. This is because a farmers's decision is sometimes strongly influenced by nonagricultural factors. Insecurity of land tenure, for instance, may inhibit investing in permanent improvements. Also, changes in the price of inputs will affect the amounts used. Such factors are usually beyond the plan. However, farmers can set the boundaries within which any improvement in land use and management must be decided, designed and implemented. Hence, the recommendations could be seen as management options for them.

The main function of the GIS in creating recommendations was to collect, manage and combine all necessary information so that they could be easily interpreted. Map overlay and database management played important roles in providing interpretative information. The capability to provide a high quality map display with accurate boundaries was one of the advantages of the GIS's vector data structure. However, the reliable recommendations in the farm soil conservation planning was greatly dependent upon the accuracy of the data in previous forms and the scale of data sources. The result of an analysis could not be more detailed than the data sources. Consequently, if data sources were not available at the scale of analysis, they needed to be supplemented by adding information from other sources and/or field observation. Despite providing a result which was based on the original objectives, the GIS could also be used to provide additional interpretations of the data that might be useful for improvements.

CHAPTER VII

GENERAL DISCUSSION AND CONCLUSIONS

General Discussion

Factors collected in the LRI were put to use in many ways. The slope factor was taken into account in both the LUC classification and the potential erosion assessment and could be seen as the most dominant factor in the whole process. Other factors such as fence details and ownership were not directly used in the analyses but information that was contained in these maps was considered in determining management practices and other additional improvements.

The functions of the GIS that were most frequently used in this study were: overlaying, database querying and map display facilities. It should be noted that composing maps using display facilities (i.e PC ARCPLOT) was very time consuming. Bigger map files would need a longer time to get hard copies either from printers or plotters. Based on this experience, it clearly shows the need for facilities which can display the results of an analysis in reasonable time.

For those who are familiar with the GIS, this problem can be solved simply by creating macro commands (i.e SML or AML), however most users who won't know too much about the GIS may need special facilities to obtain information from the results of GIS analyses without having hard copies. For this reason, one of the GIS utilities (i.e PC ARCVIEW), which is able to provide facilities of data display either in maps or in databases, was suggested for displaying results of GIS analyses. This facility was also suggested for developing more useful applications so that the data could be easily understood and users could obtain information in detail from the data display.

Conclusions

Based on the experience from this study, the GIS proved to be a reliable tool in creating a soil conservation plan at a farm scale. The starting point of the planning process was a land resources inventory where land characteristics were collected using both primary and secondary methods. Primary methods refer to methods of data collection in which data are collected directly from the field supported by air photo-interpretation, whereas secondary methods refer to data collection from existing documents such as maps and reports.

The GIS also enabled data collected in the LRI to be stored in the system, either in individual map coverages or in a database, by capturing the data using a digitizer and direct typing. The data capture was one of the crucial steps because the accuracy of data in the LRI would determine the accuracy in the following steps. The stored data was then manipulated using a database management system so that the data could be easily retrieved and made suitable for further processing.

One of the most important goals in soil conservation is to put in place land uses that provide the most protection on the most hazardous land. Thus, the next steps in the farm soil conservation planning process were to indicate potential land uses and to assess potential erosion of the land based on the data collected in the LRI. Recommendations for management practices were then defined according to this information.

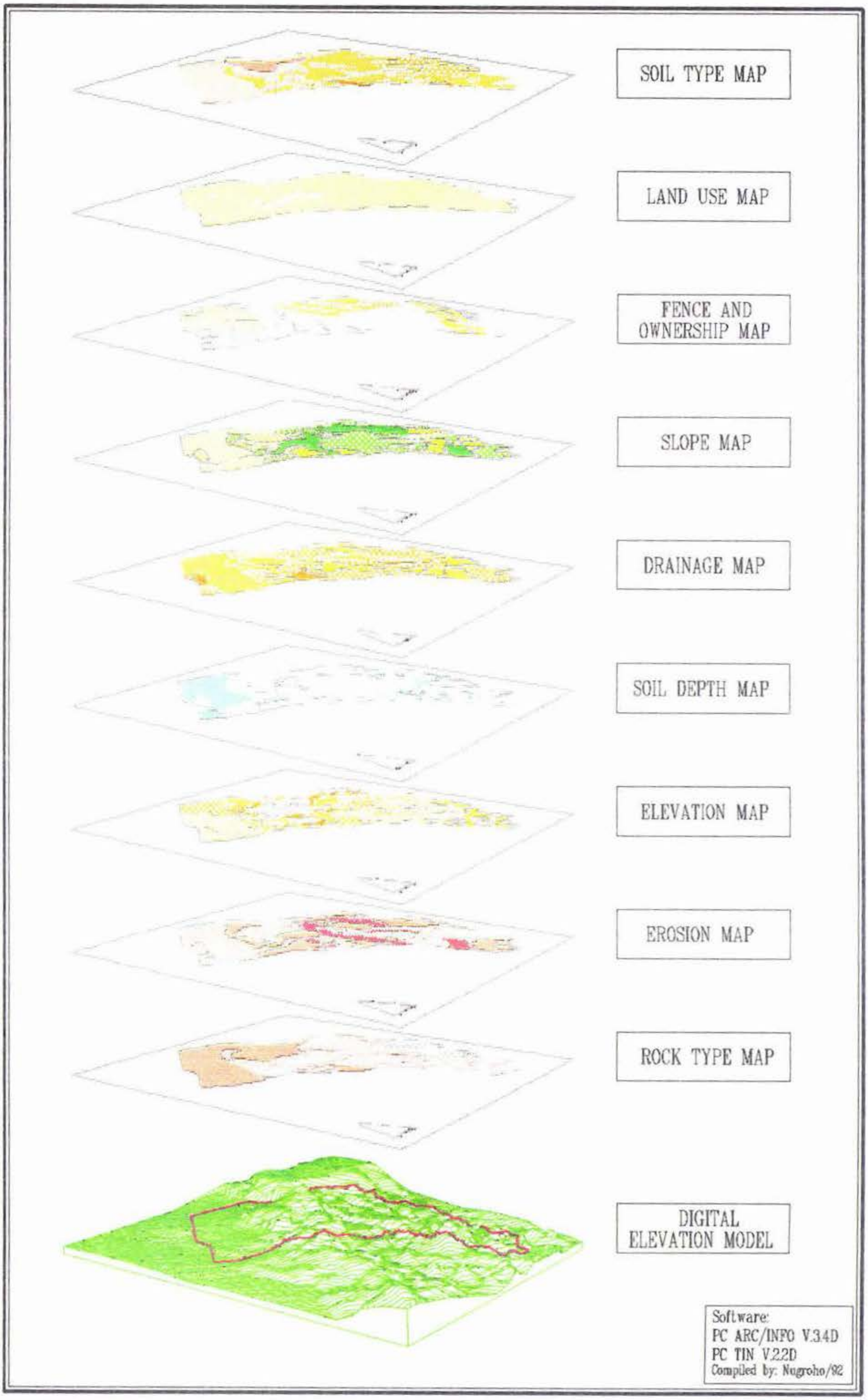
In terms of GIS operations, most analyses used in creating interpretative maps could be carried out following similar steps. The first step was to combine necessary factors from the LRI according to a set of criteria. These criteria were then expressed in macro commands and run on the database management system. The interpretative maps were derived by relating columns in the database. In this procedure, the most important step was defining the criteria for the analyses. Such database analyses make it easy for planners to alter criteria to suit different conditions or even to be used for different purposes. Alternatively, the overlaying function could be used to produce interpretative maps, however it should be noted that overlaying maps in a vector GIS is a very complicated task. Consequently, it is slower, requiring a lot of computer memory.

According to modern approaches, soil conservation should be integrated into agricultural practices. Thus, recommendations for land management practices should take the present farming system into account. Although these recommendations can be derived by utilizing information in the database, the farmers's aspirations should be included in considerations. They should be involved from the beginning of the planning process so that the interpretative maps produced from the analyses are more useful for their requirements. The resulting maps should show clearly the management options available to farmers.

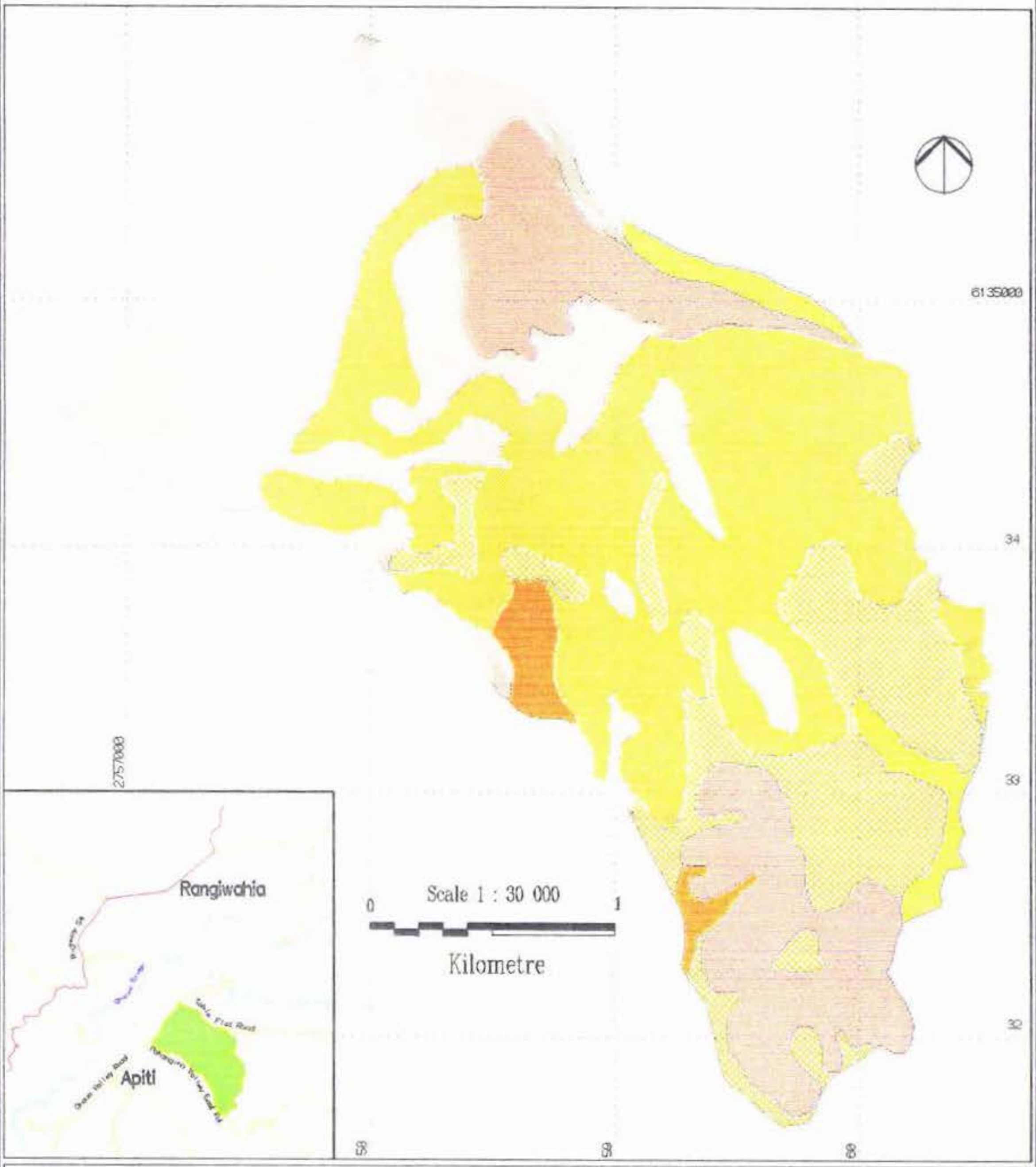
The time limits involved with this project meant it was not possible to undertake the last stage of the soil conservation planning process, that of implementing the recommendations. This would have required a significant further period to work with the participating farmers. Instead, the project successfully provided a description of a GIS technique for soil conservation planning which can be applied by local soil conservators. The technique is transportable, being applicable in any rural environment.

APPENDIX 1 :

Land Resources Inventory Factors


SOIL TYPE MAP
LAND USE MAP
FENCE AND OWNERSHIP MAP
SLOPE MAP
DRAINAGE MAP
SOIL DEPTH MAP
ELEVATION MAP
EROSION MAP
ROCK TYPE MAP
DIGITAL ELEVATION MODEL
Software:
PC ARC/INFO V.3.4D
PC TIN V.2.2D
Compiled by: Nugroho/92

SOIL TYPE MAP



LEGEND

- Dannevirke silt loam (Integrades YBL and YBE)
- Dannevirke silt loam rolling phase (Integrades YBL and YBE)
- Whetukura silt loam (YBE)
- Whetukura hill soils (YBE)
- Kiwitea fine sandy loam, rolling phase (YBE)
- Utuwai silt loam (Recent soils)

REFERENCE:
Rijkse, W C (1977) Soils of Pohangina County, North Island, New Zealand, Soil Bureau Bulletin 42, DSIR Soil Bureau, Wellington.

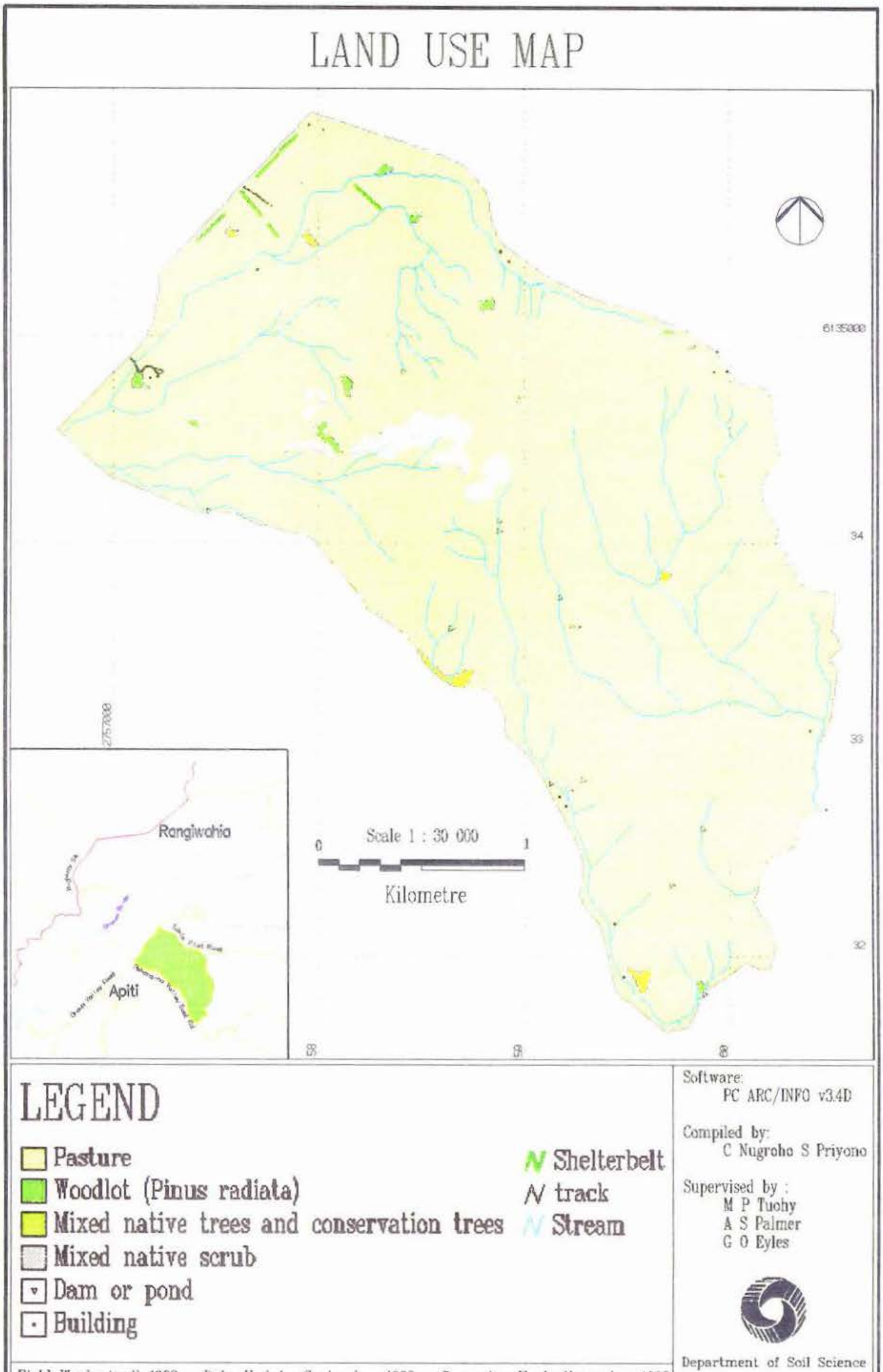
Field Work: April 1992 Data Update: September 1992 Computer Work: November 1992

Software:
PC ARC/INFO v3.4D

Compiled by:
C Nugroho S Priyono

Supervised by :
M P Tuohy
A S Palmer
G O Eyles

Department of Soil Science
MASSEY UNIVERSITY


LAND USE MAP
6135000
34
33
32
2757000
Rangiwahia
Apiti
Scale 1 : 30 000
0
1
Kilometre
LEGEND
Pasture
Woodlot (Pinus radiata)
Mixed native trees and conservation trees
Mixed native scrub
Dam or pond
Building
Shelterbelt
track
Stream
Software:
PC ARC/INFO v3.4D
Compiled by:
C Nugroho S Priyono
Supervised by :
M P Tuohy
A S Palmer
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MASSEY UNIVERSITY
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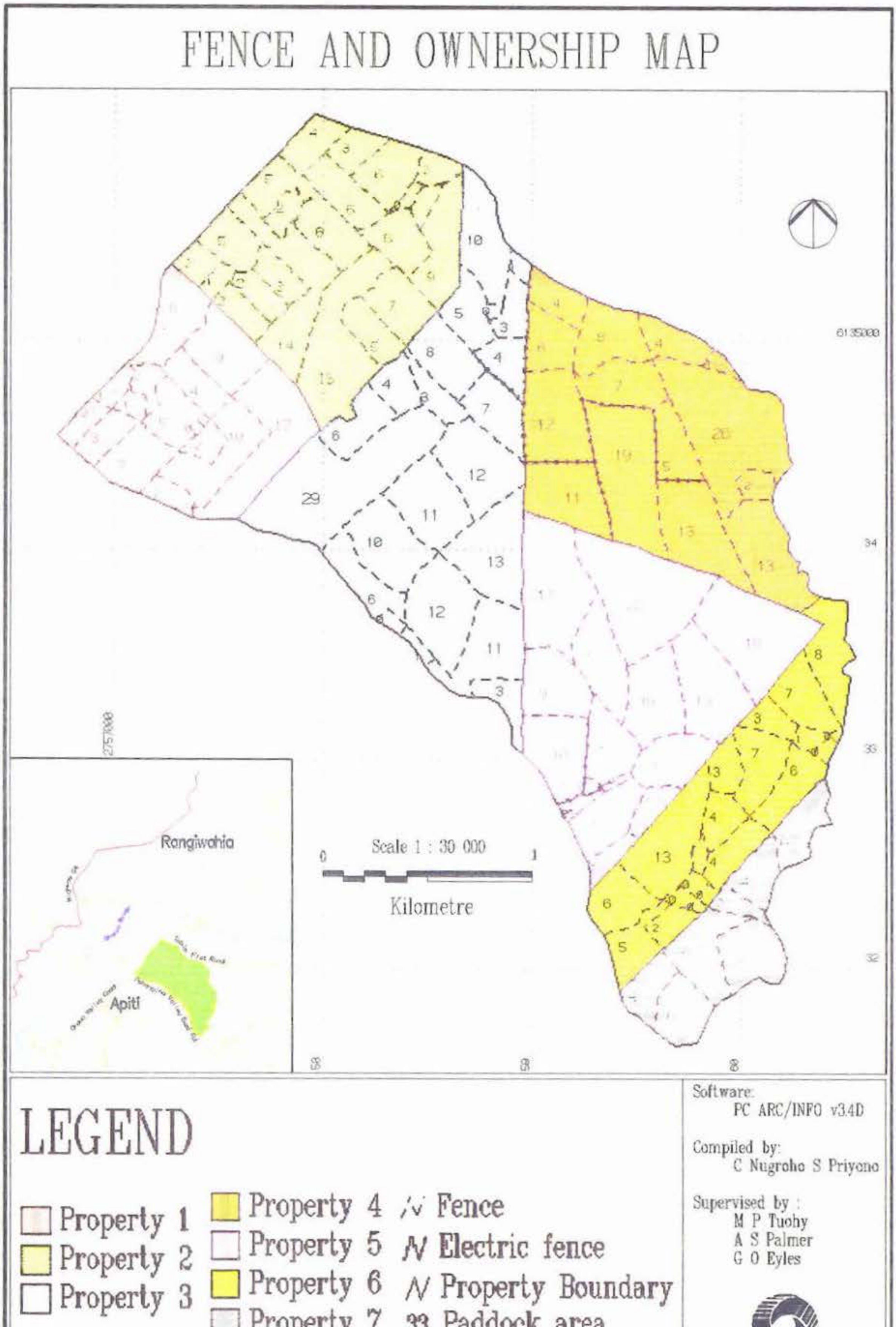
Computer Work: November 1992


FENCE AND OWNERSHIP MAP
Rangiwahia
Apiti
Scale 1 : 30 000
0
1
Kilometre
6135000
2757000
34
33
32
LEGEND
Property 1
Property 2
Property 3
Property 4
Property 5
Property 6
Property 7
Fence
Electric fence
Property Boundary
33 Paddock area
Field Work: April 1992
Data Update: September 1992
Computer Work: November 1992
Software:
PC ARC/INFO v3.4D
Compiled by:
C Nugroho S Priyono
Supervised by :
M P Tuohy
A S Palmer
G O Eyles
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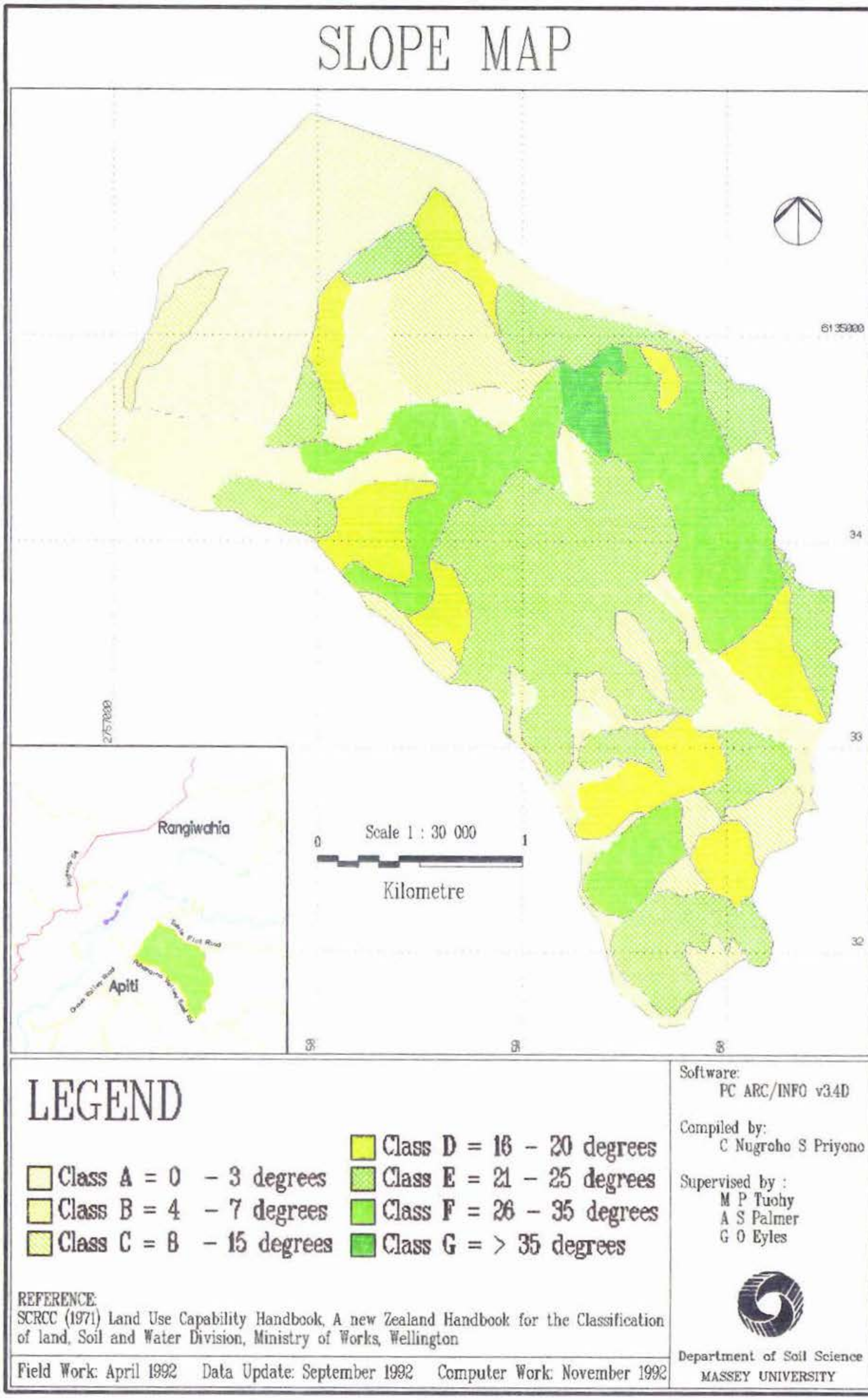
SLOPE MAP
6135000
34
33
32
2757000
Rangiwahia
Apiti
Scale 1 : 30 000
0
1
Kilometre
LEGEND
Class A = 0 – 3 degrees
Class B = 4 – 7 degrees
Class C = 8 – 15 degrees
Class D = 16 – 20 degrees
Class E = 21 – 25 degrees
Class F = 26 – 35 degrees
Class G = > 35 degrees
REFERENCE:
SCRCC (1971) Land Use Capability Handbook, A new Zealand Handbook for the Classification of land, Soil and Water Division, Ministry of Works, Wellington
Field Work: April 1992
Data Update: September 1992
Computer Work: November 1992
Software:
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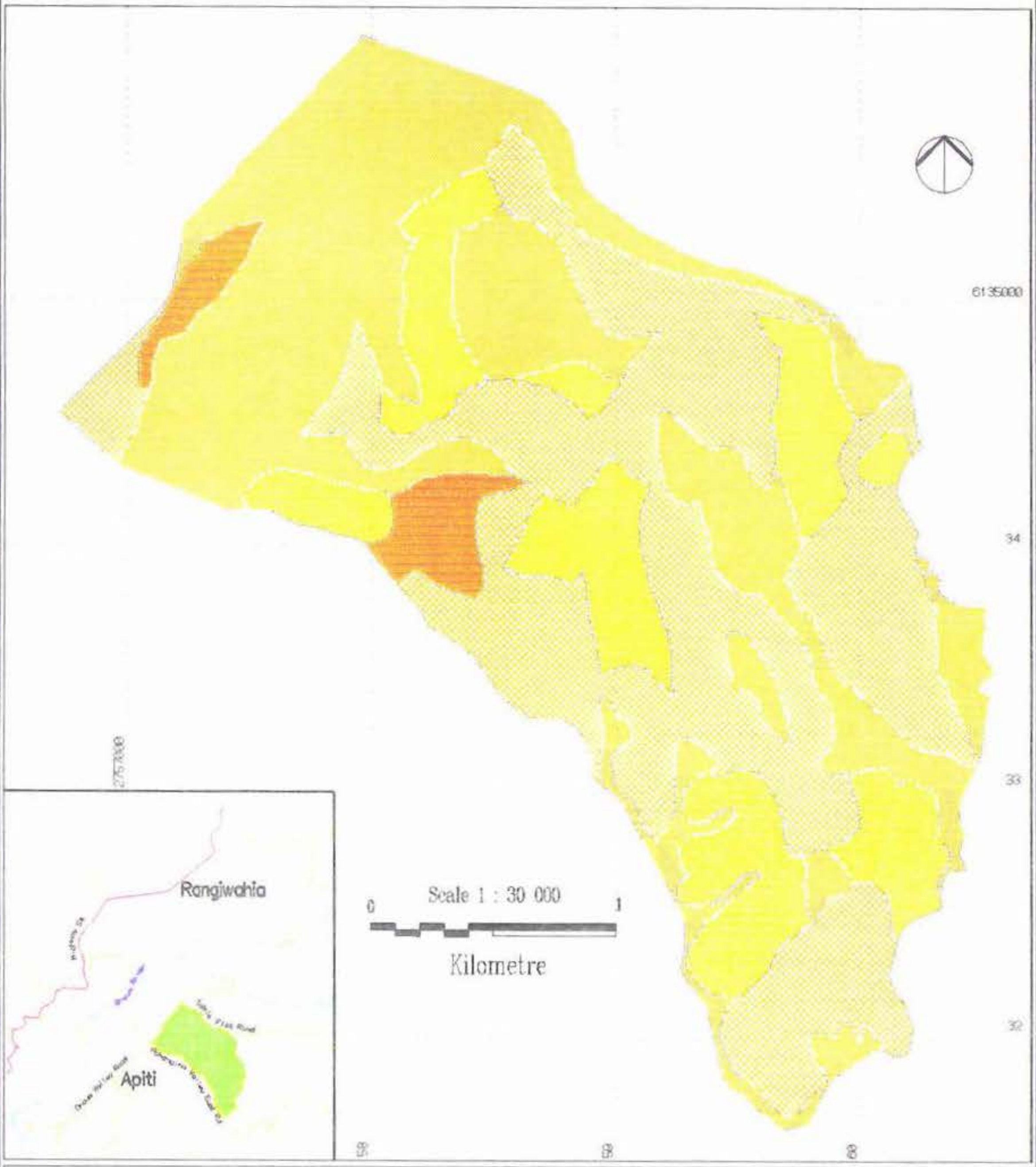
DRAINAGE STATUS MAP



LEGEND

- Very poorly drained
- Poorly drained
- Imperfectly drained
- Moderately well drained
- Well drained
- Excessively drained

Software:
PC ARC/INFO v3.4D

Compiled by:
C Nugroho S Priyono

Supervised by :
M P Tuohy
A S Palmer
G O Eyles

REFERENCE:
Taylor, N H and I J Pohlen (1962) Soil Survey Method, A New Zealand Handbook for the Field Study of Soils, Soil Bureau Bulletin 25, DSIR Soil Bureau, Lower Hutt

Field Work: April 1992 Data Update: September 1992 Computer Work: November 1992

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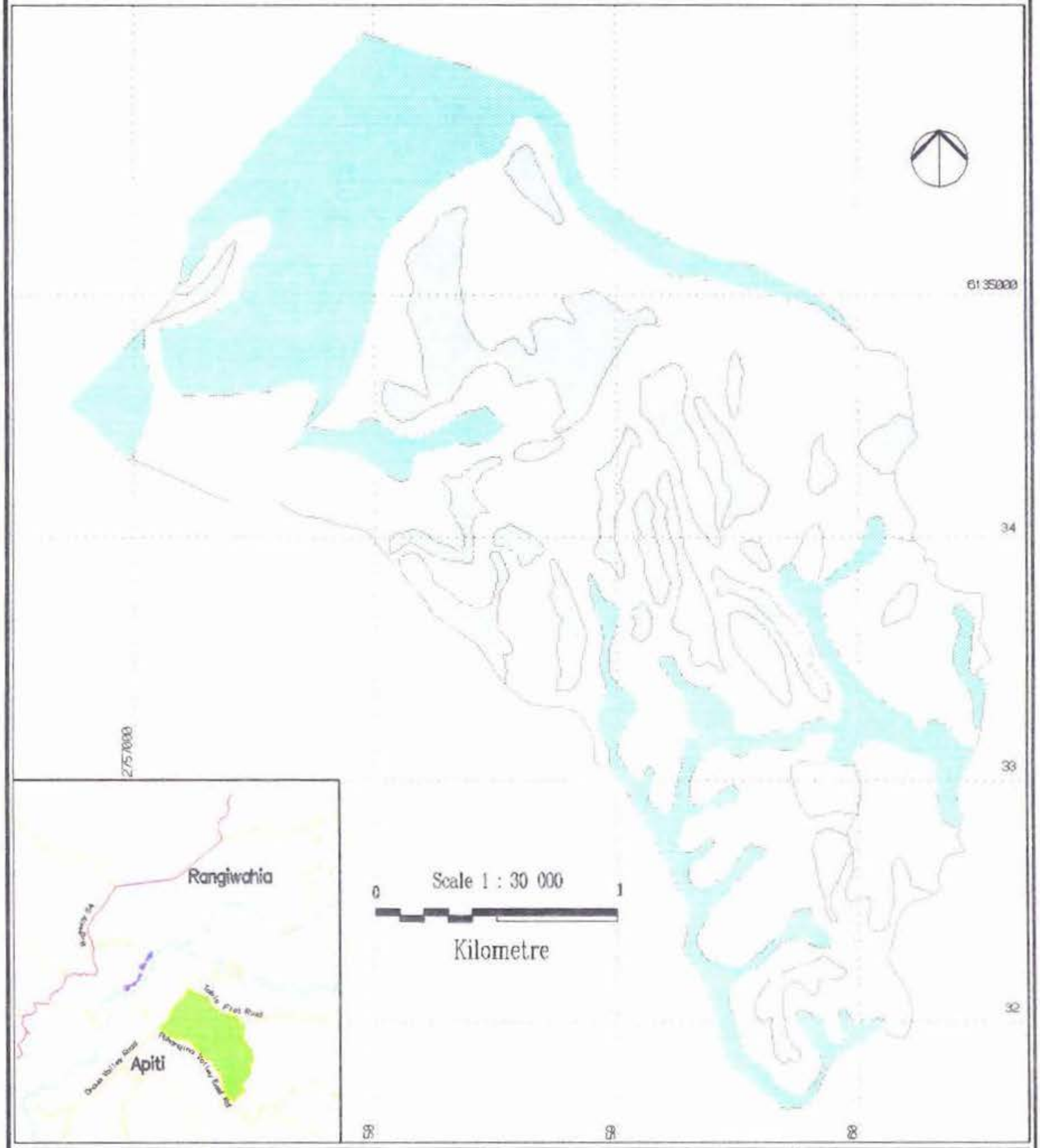
SOIL DEPTH MAP



LEGEND

- Very shallow = 0 – 15 cm
- Shallow = 16 – 45 cm
- Moderately deep = 46 – 90 cm
- Deep = 91 – 120 cm

REFERENCE:
SCRCC (1971) Land Use Capability Handbook, A new Zealand Handbook for the Classification of land, Soil and Water Division, Ministry of Works, Wellington

Field Work: April 1992 Data Update: September 1992 Computer Work: November 1992

Software:
PC ARC/INFO v3.4D

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M P Tuohy
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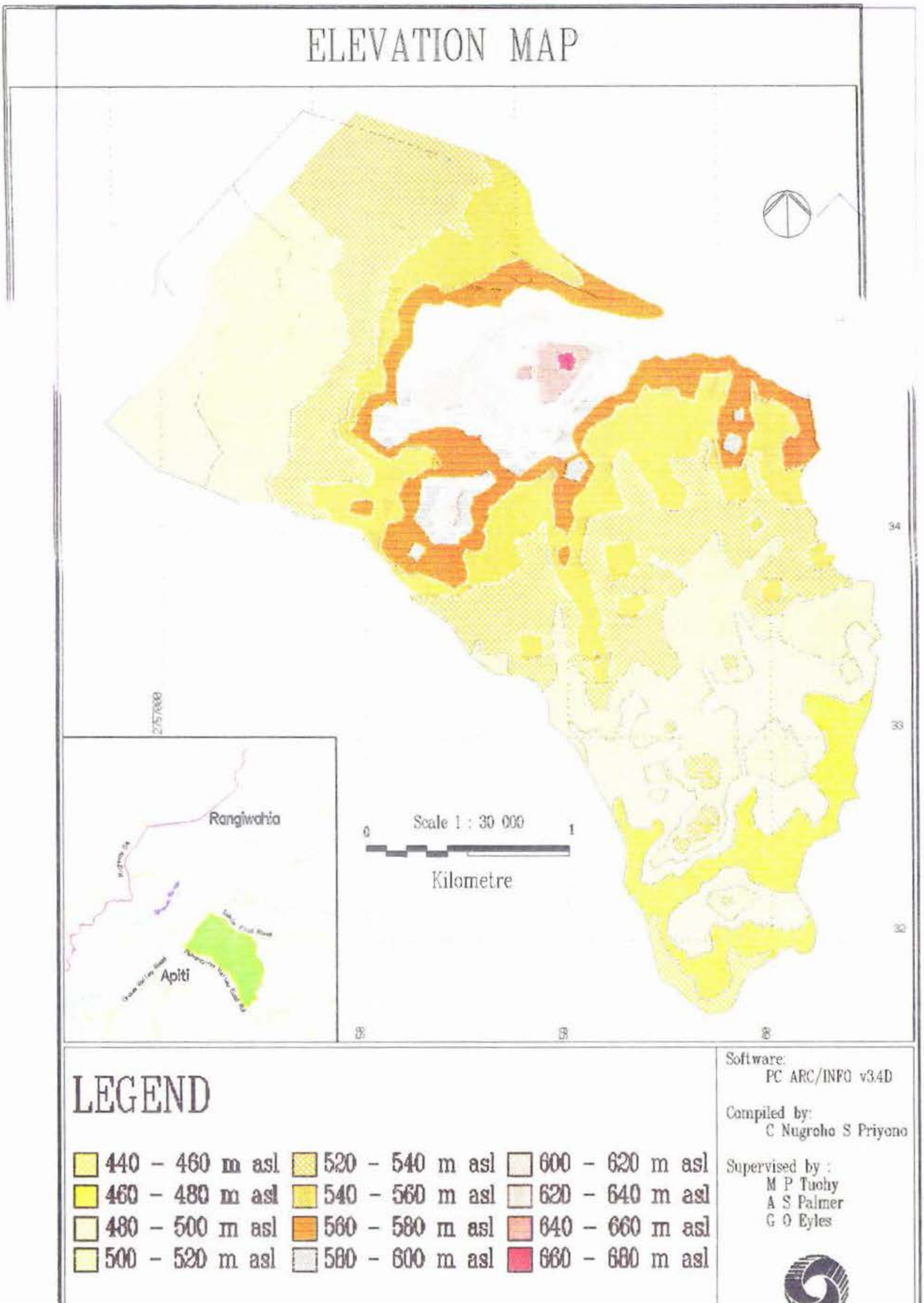
ELEVATION MAP
Rangiwahia
Apiti
Scale 1 : 30 000
0
1
Kilometre
34
33
32
LEGEND
440 - 460 m asl
460 - 480 m asl
480 - 500 m asl
500 - 520 m asl
520 - 540 m asl
540 - 560 m asl
560 - 580 m asl
580 - 600 m asl
600 - 620 m asl
620 - 640 m asl
640 - 660 m asl
660 - 680 m asl
Derived from Digital Elevation Model (DEM) of study area.
Field Work: April 1992
Data Update: September 1992
Computer Work: November 1992
Software:
PC ARC/INFO v3.4D
Compiled by:
C Nugroho S Priyono
Supervised by :
M P Tuohy
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G O Eyles
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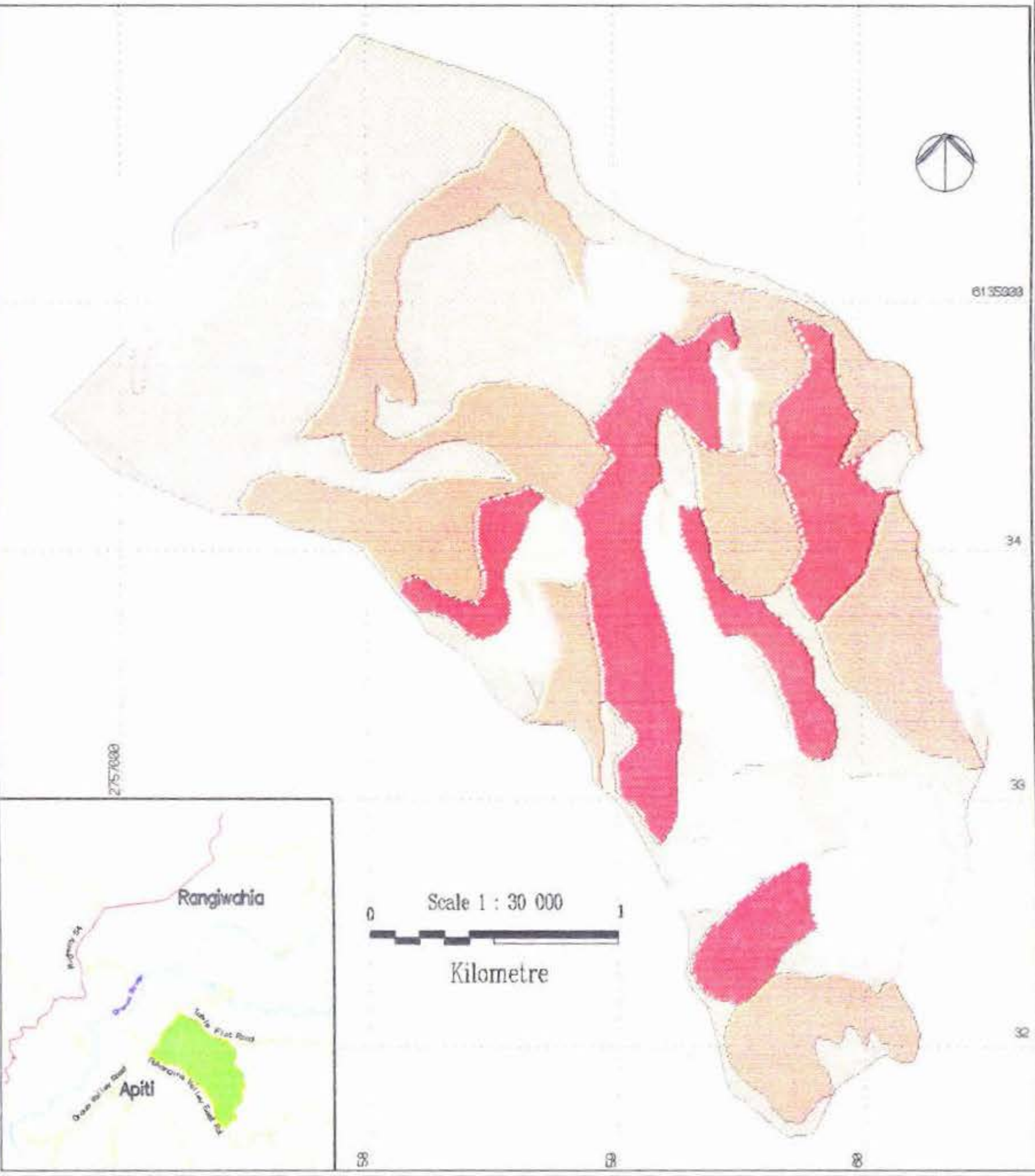
PRESENT EROSION MAP



LEGEND

- None – Very slight
- Slight
- Moderately severe
- Severe

REFERENCE:
Taylor, N H and I J Pohlen (1962) Soil Survey Method, A New Zealand Handbook for the Field Study of Soils, Soil Bureau Bulletin 25, DSIR Soil Bureau, Lower Hutt

Field Work: April 1992 Data Update: September 1992 Computer Work: November 1992

Software:
PC ARC/INFO v3.4D

Compiled by:
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G O Eyles

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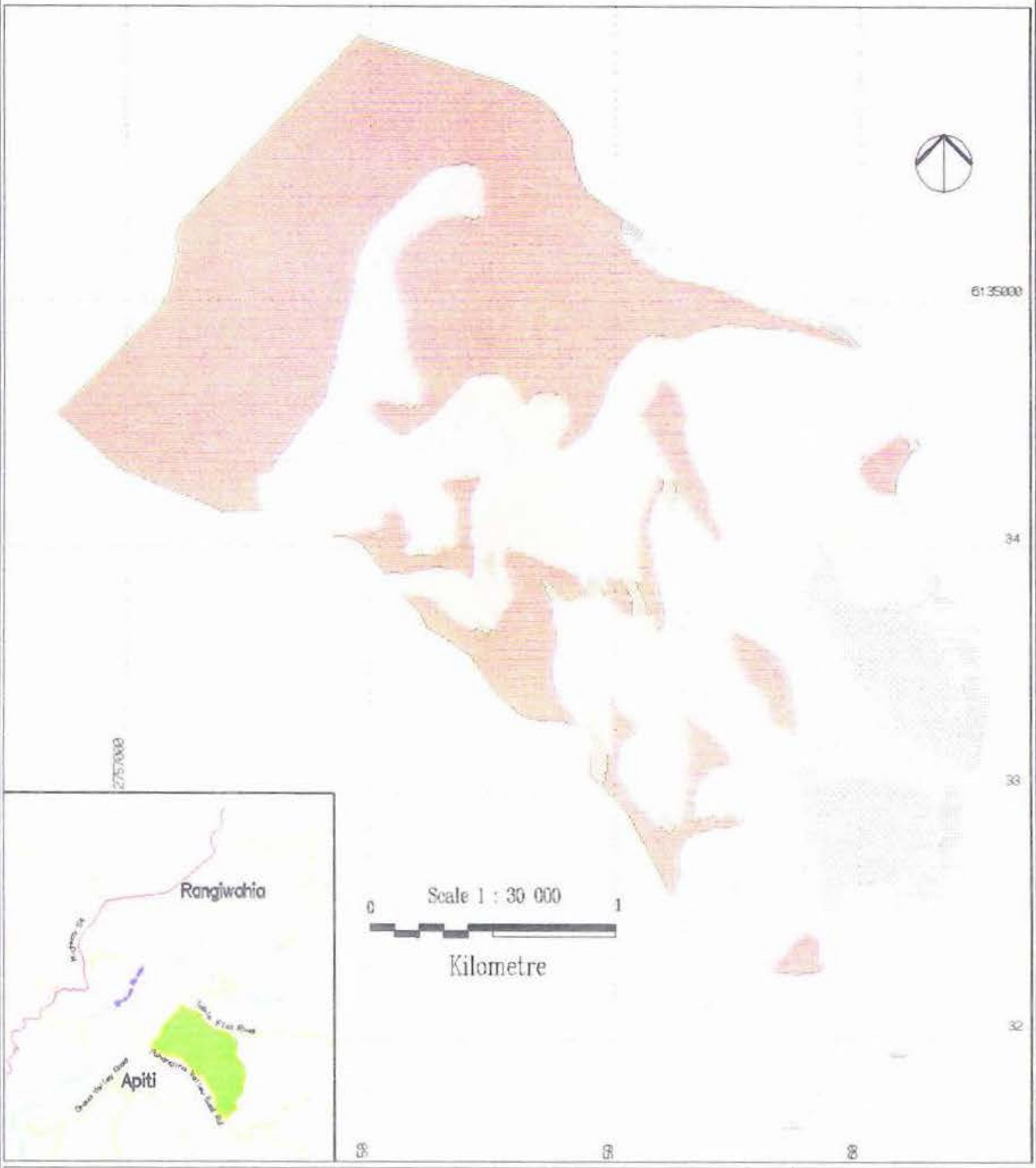
ROCK TYPE MAP



LEGEND

- Loess and tephra
- Interbedded sand-siltstones
- Alluvium/Colluvium
- Interbedded lime-sandstones

REFERENCE:
National Water and Soil Conservation (1979), New Zealand Land Resources Inventory Worksheet, Sheet N139/Mangaweka, Scale 1 : 63 360

Field Work: April 1992 Data Update: September 1992 Computer Work: November 1992

Software:
PC ARC/INFO v3.4D

Compiled by:
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M P Tuohy
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APPENDIX 2:

SML Commands to Select LUC Classes and Subclasses

```
select covluc.pat

rem class Iw
res slopeco = 1 and drainco = 4 and depthco = 4 and exeros = 1 and elev = 1
calc class = 1
move 'w' to sbcl
&type "class Iw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class Is
res slopeco = 1 and drainco = 6 and depthco = 4 and exeros = 1 and elev = 1
calc class = 1
move 's' to sbcl
&type "class Is"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class Ic
res slopeco = 1 and drainco = 5 and depthco = 4 and exeros = 1 and elev = 1
calc class = 1
move 'c' to sbcl
&type "class Ic"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIe
res slopeco = 2 and drainco in {1->5} and depthco = 3 and exeros = 2 and elev = 1
asel slopeco = 2 and drainco in {1->5} and depthco > 3 and exeros = 2 and elev = 1
calc class = 2
move 'e' to sbcl
&type "class IIe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIw
res slopeco = 1 and drainco in {3,4} and depthco = 3 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco in {3,4} and depthco > 3 and exeros = 1 and elev = 1
calc class = 2
move 'w' to sbcl
&type "class IIw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIs
res slopeco = 1 and drainco = 6 and depthco = 3 and exeros = 1 and elev = 1
```

```
asel slopeco = 2 and drainco = 6 and depthco = 3 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco = 6 and depthco > 3 and exeros = 1 and elev = 1
calc class = 2
move 's' to sbcl
&type "class IIs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIc
res slopeco in {1,2} and drainco = 5 and depthco = 3 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco = 5 and depthco = 4 and exeros = 1 and elev = 1
calc class = 2
move 'c' to sbcl
&type "class IIc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIIe
res slopeco = 2 and drainco in {1->5} and depthco = 2 and exeros = 2 and elev = 1
asel slopeco = 3 and drainco in {1->5} and depthco > 2 and exeros in {2,3} and elev = 1
calc class = 3
move 'e' to sbcl
&type "class IIIe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIIw
res slopeco = 1 and drainco in {3,4} and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 1 and drainco in {1,2} and depthco = 3 and exeros = 1 and elev = 1
asel slopeco = 1 and drainco in {1,2,3} and depthco > 3 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco in {3,4} and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco in {1->3} and depthco > 2 and exeros = 1 and elev = 1
asel slopeco = 3 and drainco in {1,2,3} and depthco > 2 and exeros = 1 and elev = 1
calc class = 3
move 'w' to sbcl
&type "class IIIw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIIs
res slopeco = 1 and drainco = 6 and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco = 6 and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 3 and drainco = 6 and depthco > 2 and exeros = 1 and elev = 1
calc class = 3
move 's' to sbcl
&type "class IIIs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IIIc
res slopeco = 1 and drainco = 5 and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco = 5 and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco = 4 and depthco > 2 and exeros = 1 and elev = 1
```

```
asel slopeco = 3 and drainco in {4,5} and depthco > 2 and exeros in {1,2} and elev = 1
calc class = 3
move 'c' to sbcl
&type "class IIIc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IVe
res slopeco = 3 and drainco = 4 and depthco = 2 and exeros in {1->5} and elev = 1
asel slopeco = 4 and drainco in {1->5} and depthco > 1 and exeros = 3 and elev = 1
calc class = 4
move 'e' to sbcl
&type "class IVe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IVw
res slopeco in {1,2} and drainco in {1,2} and depthco = 2 and exeros = 1 and elev = 1
asel slopeco = 3 and drainco in {1,2,3} and depthco = 2 and exeros in {1,2} and elev = 1
calc class = 4
move 'w' to sbcl
&type "class IVw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IVs
res slopeco = 3 and drainco = 6 and depthco = 2 and exeros in {1,2} and elev = 1
calc class = 4
move 's' to sbcl
&type "class IVs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class IVc
res slopeco = 3 and drainco in {4,5} and depthco = 2 and exeros in {1,2} and elev = 1
calc class = 4
move 'c' to sbcl
&type "class IVc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class Vw
res slopeco = 1 and drainco in {1,2,3} and depthco = 1 and exeros = 1
asel slopeco = 1 and drainco in {1,2,3} and depthco > 1 and exeros = 1 and elev = 2
asel slopeco = 2 and drainco in {1,2,3} and depthco = 1 and exeros in {1,2}
asel slopeco = 2 and drainco in {1,2,3} and depthco > 1 and exeros in {1,2} and elev = 2
asel slopeco = 3 and drainco in {1,2,3} and exeros in {1,2}
asel slopeco = 4 and drainco in {1,2,3} and depthco > 1 and exeros in {1,2}
calc class = 5
move 'w' to sbcl
&type "class Vw"
list slopeco depthco exeros elev drainco class sbcl
asel
```

```
&rem class Vs
res slopeco = 1 and drainco in {4->6} and depthco = 1 and exeros = 1 and elev = 1
asel slopeco = 2 and drainco in {4->6} and depthco in {1,2} and exeros in {1,2} and elev = 1
asel slopeco = 3 and drainco in {4,5,6} and depthco = 1 and exeros in {1,2} and elev = 1
asel slopeco = 4 and drainco in {4,5,6} and depthco > 1 and exeros in {1,2}
asel slopeco = 5 and drainco in {4->6} and depthco > 1 and exeros in {1,2}
calc class = 5
move 's' to sbcl
&type "class Vs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class V c
res slopeco = 1 and drainco in {4,5,6} and exeros = 1 and elev = 2
asel slopeco = 2 and drainco in {4,5,6} and exeros in {1,2} and elev = 2
asel slopeco = 3 and drainco in {4,5,6} and exeros in {1,2} and elev = 2
asel slopeco = 4 and drainco in {4->6} and depthco > 1 and exeros in {1,2} and elev = 2
asel slopeco = 5 and drainco in {4->6} and depthco > 1 and exeros in {1,2} and elev = 2
calc class = 5
move 'c' to sbcl
&type "class Vc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VI e
resel slopeco = 4 and drainco in {1->5} and depthco = 1 and exeros = 3
asel slopeco = 5 and drainco in {1->5} and depthco > 1 and exeros in {3,4}
asel slopeco = 6 and drainco in {1->5} and depthco > 1 and exeros = 3
asel slopeco = 7 and drainco in {1->5} and depthco > 1 and exeros = 3
calc class = 6
move 'e' to sbcl
&type "class VIe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIw
res slopeco = 4 and drainco in {1,2,3}  and depthco = 1 and exeros in {1,2}
asel slopeco = 5 and drainco in {1->3} and depthco = 1 and exeros in {1,2}
asel slopeco = 6 and drainco in {1,2,3} and depthco > 1 and exeros in {1,2}
calc class = 6
move 'w' to sbcl
&type "class VIw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIs
res slopeco = 4 and drainco in {3->6} and depthco = 1 and exeros in {1,2} and elev = 1
asel slopeco = 5 and drainco in {4,5,6} and depthco = 1 and exeros in {1,2} and elev = 1
asel slopeco = 6 and drainco in {4,5,6} and depthco > 1 and exeros in {1,2} and elev = 1
calc class = 6
move 's' to sbcl
&type "class VIs"
list slopeco depthco exeros elev drainco class sbcl
```

```
asel

&rem class VIc
res slopeco = 4 and drainco in {4->6} and depthco = 1 and exeros in {1,2} and elev = 2
asel slopeco = 5 and drainco = 4 and depthco = 1 and exeros in {1,2} and elev = 2
asel slopeco = 6 and drainco in {4,5,6} and depthco > 1 and exeros in {1,2} and elev = 2
calc class = 6
move 'c' to sbcl
&type "class VIc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VII e
res slopeco = 6 and drainco in {1->5} and depthco = 1 and exeros in {3,4}
asel slopeco = 6 and drainco in {1->5} and depthco > 1 and exeros = 4
asel slopeco = 7 and drainco in {1->5} and depthco > 1 and exeros in {4,5}
asel slopeco = 7 and drainco in {1->5} and depthco = 1 and exeros = 3
calc class = 7
move 'e' to sbcl
&type "class VIIe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIIw
res slopeco = 6 and drainco in {1,2,3} and depthco = 1 and exeros in {1,2}
asel slopeco = 7 and drainco in {1,2,3} and depthco > 1 and exeros in {1,2}
calc class = 7
move 'w' to sbcl
&type "class VIIw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VII s
res slopeco = 6 and drainco in {4->6} and depthco = 1 and exeros in {1,2}
asel slopeco = 7 and drainco in {4->6} and depthco > 1 and exeros in {1,2}
calc class = 7
move 's' to sbcl
&type "class VIIs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIIc
res slopeco = 6 and drainco in {4,5} and depthco = 1 and exeros in {1,2} and elev = 2
asel slopeco = 7 and drainco in {4,5} and depthco > 1 and exeros in {1,2} and elev = 2
calc class = 7
move 'c' to sbcl
&type "class VIIc"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIIIe
res slopeco = 7 and drainco in {1->6} and depthco = 1 and exeros in {4,5}
calc class = 8
```

```
move 'e' to sbcl
&type "class VIIIe"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIII w
res slopeco = 7 and drainco in {1,2,3} and depthco = 1 and exeros in {1->5}
calc class = 8
move 'w' to sbcl
&type "class VIIIw"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIIIs
res slopeco = 7 and drainco in {4,5,6} and depthco = 1 and exeros in {1,2} and elev = 1
calc class = 8
move 's' to sbcl
&type "class VIIIs"
list slopeco depthco exeros elev drainco class sbcl
asel

&rem class VIIIc
res slopeco = 7 and drainco in {4,5,6} and depthco = 1 and exeros in {1,2} and elev = 2
calc class = 8
move 'c' to sbcl
&type "class VIIIc"
list slopeco depthco exeros elev drainco class sbcl
asel

resel class = 0
list area slopeco depthco exeros elev drainco class sbcl
```

APPENDIX 3:

SML Commands to Calculate Total Area of Each Class and Subclass

```
sel covluc.pat

&openw elarea.txt

&write "class Iw"
resel class = 1
stat area
asel

&write "class IIc"
resel class = 2
stat area
asel

&write "class IIIw"
resel class = 3 and sbcl eq 'w'
stat area
asel
&write "class IIIc"
resel class = 3 and sbcl eq 'c'
stat area
asel

&write "class IVe"
resel class = 4 and sbcl eq 'e'
stat area
asel
&write "class IVc"
resel class = 4 and sbcl eq 'c'
stat area
asel

&write "class Vw"
resel class = 5 and sbcl eq 'w'
stat area
asel
&write "class Vs"
```

```
resel class = 5 and sbcl eq 's'
stat area
asel
&write "class Vc"
resel class = 5 and sbcl eq 'c'
stat area
asel

&write "class VIe'
resel class = 6 and sbcl eq 'e'
stat area
asel

&write "class VIw"
resel class = 6 and sbcl eq 'w'
stat area
asel
&write "class VIs"
resel class = 6 and sbcl eq 's'
stat area
asel

&write "class VIIe"
resel class = 7 and sbcl eq 'e'
stat area
asel
```

APPENDIX 4:

SML Commands for Potential Erosion Assessment

```
sel erospot.pat

&rem Not Susceptible to erosion
resel slopeco in {1,2} and rocksco = 4 and soilco = 6
calc proneros = 1
calc comb = 1
asel
resel slopeco in {1,2} and rocksco = 2 and soilco in {1,2}
calc proneros = 1
calc comb = 2
asel

&rem Slight susceptibility to erosion
resel slopeco in {3,4} and rocksco = 3 and soilco = 3
calc proneros = 2
calc comb = 3
asel
resel slopeco in {3,4} and rocksco = 5 and soilco = 3
calc proneros = 2
calc comb = 4
asel
resel slopeco in {3,4} and rocksco = 2 and soilco in {1,5}
calc proneros = 2
calc comb = 5
asel

&rem moderate susceptibility to erosion
resel slopeco = 5 and rocksco = 3 and soilco in {3,4}
calc proneros = 3
calc comb = 6
asel
resel slopeco = 5 and rocksco = 5 and soilco = 3
calc proneros = 3
calc comb = 7
asel

&rem high susceptibility to erosion
resel slopeco in {6,7} and rocksco = 3 and soilco = 4
calc proneros = 4
```

```
calc comb = 8
asel
resel slopeco in {6,7} and rocksco = 5 and soilco = 3
calc proneros = 4
calc comb = 9
asel

list area slopeco rocksco soilco proneros comb
```

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