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Assessing chronological changes in remnant native forest at catchment level : a case study on the Toolibin catchment area

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Department of Agriculture
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ASSESSMENT OF CHANGES IN REMNANT NATIVE FOREST AT CATCHMENT LEVEL

Prepared by Graciela Metternicht and Greg Beeston

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Assessing chronological changes in remnant native forest at catchment level

A case study on the Toolibin catchment area

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February 2002

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Summary

This report summarises applied research work undertaken during January-December 2000 within the frame of the SPIRT project 'Rapid assessment and monitoring of vegetation conditions within agricultural landscapes'. It partly meets the following expected outcomes:

- An assessment and monitoring system for rapid assessment of vegetation conditions, that integrates remote sensing techniques with ground-based sampling using global positioning systems for geo-referencing, relational data bases and geographic information systems, providing a wide range of products designed to meet user needs.
- Verification that the condition of remnant vegetation can be used as an overall indicator of environmental health.
- Improvement of the scientific basis for management of existing remnant vegetation, by providing a methodology to monitor revegetation programs aimed at redressing problems of land degradation across the agricultural region.
- Manuscripts, workshops, conference presentations and papers at national and international scientific magazines, reporting on the findings of the project.

The Toolibin catchment was selected as one of the pilot study areas. The specific objectives study were:

- To construct a digital database of the historical patterns of land clearing (amount, spatial distribution);
- To reconstruct the historical vegetation of the catchment using mallet maps produced in the 1890s and 1900s , and reports of the period;
- To produce maps showing the rate of clearing for the periods 1960-70, 1970-80, 1980-1996; and
- To analyse the relationship between soil types, topographic position and land clearing.

It is the first time such GIS-based spatial data analysis, integrating archive information on land clearing, historical aerial photographs and current soil maps is undertaken for the catchment of Toolibin. A new 'historical data base' was designed to store the information provided by the mallet maps. The disparity in the format, scale and accuracy of the data collected for spatial analysis of land clearing determined errors during the process of data integration. Therefore, standards were set to reduce the spatial errors emerging during the production of the historical digital mosaics, and the problem of conflation arising when overlaying multi-temporal vector information derived from such mosaics. These procedures are described in the methodology section of this report.

MGE, Geomedia, Access database and MFWork software were used during the project to ensure easy integration of the information generated, with the existing database of the Department of Agriculture. Multi-temporal layers of remnant vegetation were digitised in a vector environment. A simple vegetation classification

scheme presented in Table 3.2 was developed. Such scheme was kept simple so that the classes could still be identified and mapped on the historical black and white aerial photographs at scale 1:40,000. Detailed fieldwork on floristic composition and status of the vegetation stratum was conducted in one transect by SPIRT collaborators (see Figure 3.6 and Appendix).

Remnant, non-remnant, cleared and regrowth vegetation classes were adopted for the multi-temporal spatial analysis and modelling of land clearing. These broad classes were adopted because the main focus was on mapping the rate of land clearing, the spatial location of such clearing, the relationship between land clearing and soil types, and spatial location of revegetated areas in the period 1900s-1996.

The name 'historical layers' is used to identify the historical record derived from the surveys of the classification and valuation forms. Most of these records are located in the eastern side of the catchment (Figure 3.8). The historical soil records covered 1 per cent of the area (see Figure 3.10), while the vegetation records covered approximately 2 per cent, mainly around the catchment boundaries (Figure 3.11).

An 11-class vegetation scheme was devised to group the variety of information on vegetation collected from the historical surveys (see Table 3.3). Soils were grouped in three classes (i.e. first, second and third class soils), and their dominant textural composition analysed (Figure 3.14). First class soils are characterised by loamy and clay loam textures, or described as good to fair soils in the mallet maps. Second class soils are characterised by a larger variety of soil textures, and general descriptions of good and fair soil types. Sandy and gravelly, sandy loam, and sandy textures predominate, with gravelly, gravelly loam, sandy clay, and clayey soils to a lesser extent. Third class soils are of poor quality, with presence of ironstones in several soil units. Sandy and sandy and gravelly textures are predominant, with lower amounts of gravelly and sandy clayey soil textures.

Using combined knowledge of soils, vegetation and slope information, sets of rules and alternative 'historical models' were devised to reconstruct the conditions of the landscape at the beginning of the last century.

The spatial analysis of historical data and multi-temporal aerial photographs conducted during this project, described in Sections three and four, showed that 87 per cent of the catchment area has been cleared for agricultural purposes. Small stands of native vegetation (ranging from less than one hectare to between 200 and 500 hectares - see Table 4.4) covered 13 per cent of the catchment by 1996. Three per cent of the catchment was recognised as revegetated areas in 1996. Our study shows that over the period 1962 to 1996 approximately 5,430 hectares of remnant vegetation were cleared.

Tables 4.1 to 4.4 present the characteristics of the patches of remnant vegetation in the period 1962, 1972, 1983 and 1996. These tables show the progressive fragmentation of the landscape. Table 4.6 presents the changes in vegetation for each time period analysed. The highest rate of clearing occurred from 1962 to 1972 (34 per cent). Large areas were cleared, widespread over the entire catchment (Figure 4.1). During 1972-1983 (Figure 4.2), the clearing of large areas decreased (20 per cent), being limited to three large areas on the margins of the western and eastern boundaries of the catchment, and some smaller central areas. Table 4.6

shows changes in vegetation over a 34-year period. Clearing reduced considerably in the period 1983-1996 (3 per cent). This may be the result of the catchment management plan instigated then. Revegetation was most pronounced in the 1983 to 1996 period, as it would be expected as a result of the catchment management plan implementation. Areas mapped as revegetated occur mainly through the centre of the catchment, predominantly on the flatter slopes, along the lakes and through the eastern boundary. The bulk of revegetation has occurred on slopes between zero and 3 per cent inclusive (Table 4.11). The amount of native land cover halved over the 34-year period considered in this study.

A/Prof Graciela Metternicht

Chief Investigator

Contents

1. Aims

The aims of this study were:

1. To construct a digital database of the historical patterns land clearing (amount, spatial distribution)
2. To reconstruct the historical vegetation of the catchment using mallet maps and reports of the period
3. To produce maps showing the rate of clearing for the periods 1960-70, 1970-80, 1980-1996
4. To analyse the relationship between soil types, topographic position and land clearing.

2. Description of Toolibin catchment

2.1 Location

Toolibin Lake catchment is located 240 km south-east of Perth, Western Australia and 4 kilometres south-east of the township of Wickepin. Most of the Wickepin shire is covered by the Toolibin Lake Catchment, approximately 48,000 hectares in area. The lake itself is located 32 55' S, 117 36' E; 17 kilometres south-east of Wickepin in the Avon Wheatbelt bioregion.

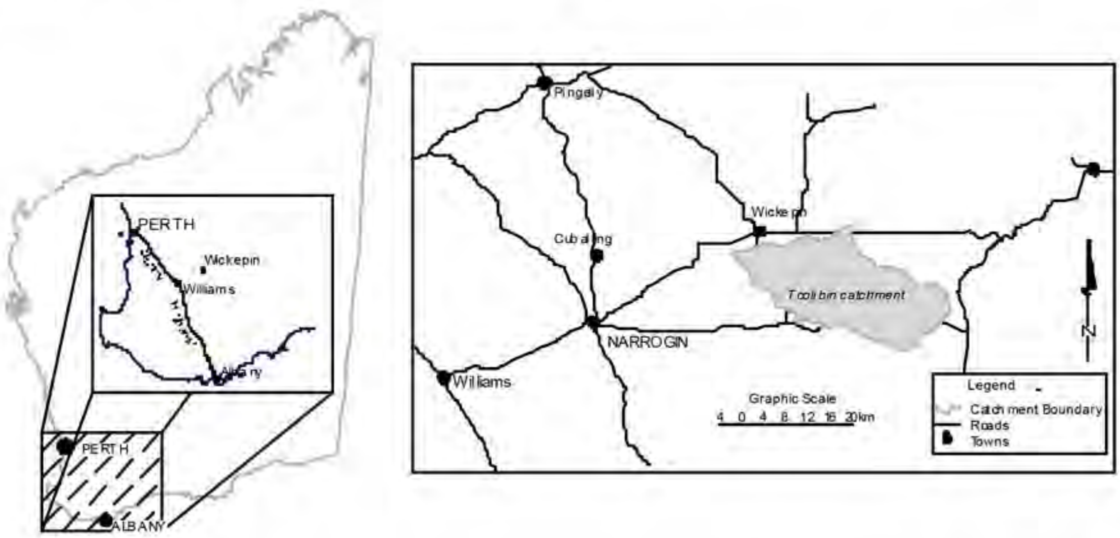


Figure 2.1: Study area location

2.2 Climate

The climate is Mediterranean with cool wet winter growing seasons and warm to hot summers. Annual rainfall varies from 375 mm in the east of the catchment to 425 mm in the west (Baxter 1996) with most rain between May and August. Annual average evaporation is about 1900 mm (George 1998). The climate statistics shown in Table 2.1 are based on recordings made at the Narrogin site (32.94 S, 117.18 E, elevation 338 m) (www.bom.gov.au/climate/averages/tables/cw). The records for

Narrogin commenced in 1891. The number of years is calculated as the number of months whose records were used divided by 12. It is not referring to calendar or complete years except for the rainfall decile values.

The percentage complete refers to how complete the data is for that element, if the percentage complete is 100 it indicates there are no missing records between the two dates. Some of the readings may have more data available than others, therefore the percentage complete and number of years data varies between different elements.

Table 2.1 Climatic data for the Narrogin area

Month	Mean daily maximum temperature (^{0}C)	Mean daily minimum temperature (^{0}C)	Mean rainfall (mm)	Mean number of clear days	Mean daily evaporation
January	30.9	14.6	12.4	16.0	8.8
February	29.9	14.7	16.8	12.4	7.7
March	27.2	13.6	20.8	10.9	6.0
April	22.9	11.0	29.8	7.4	3.5
May	18.5	8.1	64.5	6.0	2.3
June	15.5	6.9	89.8	4.9	1.6
July	14.7	5.8	89.3	5.1	1.5
August	15.3	5.7	68.6	4.9	2.0
September	17.4	6.4	47.2	5.3	2.8
October	21.2	8.0	33.4	6.4	4.2
November	25.0	10.6	17.9	7.7	5.9
December	28.9	13.0	13.3	13.0	8.0
Annual	*22.3*	*9.8*	*503.8*	*100.0*	*4.5*
No of years	31.5	30.9	109.1	33.3	12.3
% complete	89	87	100	94	66

2.3 Soils and landscape units

The west of the Toolibin catchment is typical of the zone of dissected drainage characterised by partially stripped and shallower soils ('woolbelt'), while the eastern portion is typical of the soils and landforms of the Zone of Ancient Drainage that is flat, deeply weathered, deep regolith 'wheatbelt' (George 1998). The 'Zone of Ancient Drainage' is described as broad flat valleys of low gradient with salt lake chains at their lowest point, gently sloping valley sides, some rock outcrops and large areas of yellow sandplain (Baxter 1996). Broad valley flats occupy approximately 25 per cent of the catchment.

Three soil-landscape systems occur in the catchment (Verboom and Galloway 1999):

1. Coblinine System (Cb259 on Figure 2.2): Broad valley floors in the south-western Zone of Ancient Drainage (Blackwood Catchment), with saline wet soil, alkaline grey shallow sandy duplex and deep sandy duplex. Salmon gum-wandoo woodland, mallee scrub and samphire flats. Occurs in the

low-lying areas through the centre of the catchment and the lakes. Comprises approximately 19 per cent of catchment.

2. Whinbin System (Wb257): Undulating rises, in the southern Zone of Rejuvenated Drainage. Grey sandy duplex (mostly deep), sandy gravel and alkaline red shallow loamy duplex. Wandoo-rock sheoak woodland. On margins of the western boundary (about 5 per cent of the catchment).

3. Dongolocking System (Do259): Gently undulating to undulating rises and low hills, in the south-western Zone of Ancient Drainage (Blackwood Catchment). Grey deep sandy duplex, sandy gravel and shallow sandy duplex. Wandoo-sheoak woodland and mallee. Covers about 75 per cent of the catchment.

The Kweda System (Ke259) and Arthur River System (Ar257) surround parts of the catchment boundary.

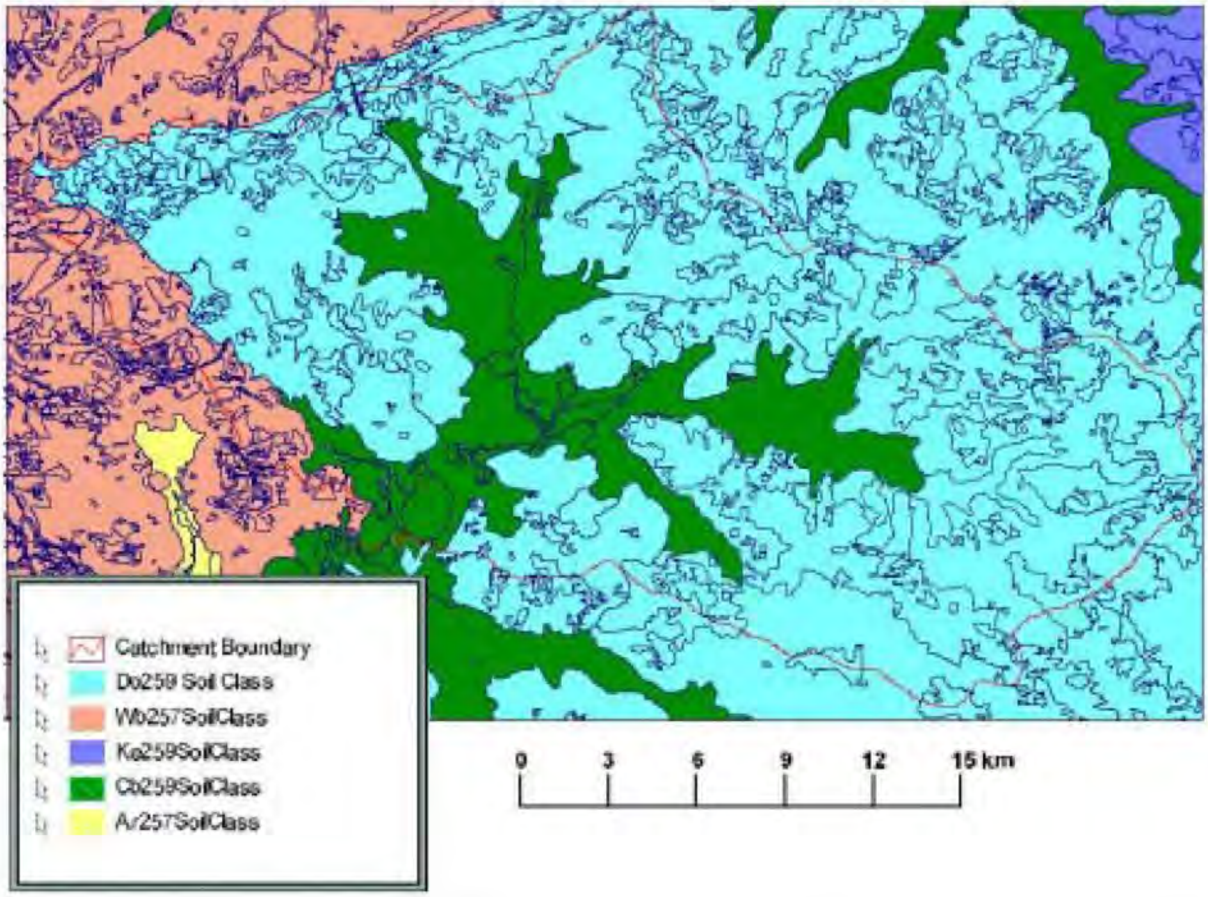


Figure 2.2: Map of current recognised soil-landscape systems in the Toolibin catchment

The flats contain mainly hardsetting grey clays and duplex soils (sand over clay). Hillslopes are mainly duplex soils with sand from 20 to 50 cm deep. Upper slope soils are sandy gravels and sandplain, with seams of deep infertile grey sand occupying approximately 4.2 per cent of the catchment (Baxter 1996). Upper slopes can also have ironstone hills and granite outcrops.

2.4 Land use

The spatial analysis of historical data and multi-temporal aerial photographs conducted during this project, described in Sections 3 and 4, showed that 87 per cent of the catchment has been cleared for agricultural purposes. Small stands of native vegetation (ranging from less than 1 ha to between 200 and 500 ha – see Table 4.4) covered 13 per cent of the catchment by 1996. Three per cent of the catchment was revegetated areas in 1996. Our study shows that over the period 1962 to 1996 approximately 5,430 hectares were cleared. Settlers first entered the region in which Toolibin lies in the 1890s. Initial activities included gathering sandalwood and ranging sheep. Clearing began about 1905 and up until World War I clearing was localised to 12 properties to the south east of Lake Toolibin (Casson 1987). There were two main periods of clearing. The first, from post-World War I up to the time of the Great Depression concentrated on the heavier soils under salmon gum (*Eucalyptus salmonophloia)*, York gum (*E. loxophleba)* and morrel (*E. longicornis*). The second, after World War II involved clearing the lighter sandier soils with the focus of the late 1940s and early 1950s being the valley sides vegetated with wandoo (*E. wandoo*) and jam (*Acacia acuminata*) (Casson 1987). Approximately one third of the clearing had occurred by the mid-1930s with the remainder in the late 1940s and early 1950s (Halse 1987). The clearing process continued, with 85 per cent of the catchment cleared by 1960 (Casson 1987). The catchment is dominated by dryland agriculture, based on crops such as wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena byzantina*), lupins (*Lupins consentini, L. albus*) and canola (*Brassica napus*), and pastures mainly for sheep.

2.5 Major catchment position

The catchment forms the headwaters of the Arthur River in the Blackwood River catchment. Toolibin is part of an area of ancient valleys and drainage lines that have poor external drainage. Toolibin Lake is the first of nine lakes that form a chain that only occasionally overflow and discharge into the Blackwood River (Baxter 1996). This means that Toolibin Lake has control of its own water. The catchment has two active catchment groups (West Toolibin and Scriveners Soak - eastern catchment) and a long history of soil and land conservation activities (George 1998).

2.6 Geology

The geology of the region is a combination of undifferentiated Archaean granitoid rocks covered by large areas of Cainozoic and Quaternary regolith materials, with only limited (about five) outcrops present (Corrigin 1:250,000 Map sheet, Chin 1986). A single major Proterozoic dyke (Bineringie, ENE trending) was mapped in the north-west of the catchment, with six smaller dykes (as linear segments) mapped in the remainder (George 1998)

2.7 Hydrology

Recharge is the process where rain passes beyond the roots of vegetation to join the groundwater system, causing groundwater to rise. It was thought recharge mainly occurred on the sands and gravels of the upper slopes but in the lower catchment (Toolibin Flats) groundwater recharge was noted in both the uplands (sandplain) and valley floor (matrix and preferential flow) (George 1998). Recharge, resulting from rainfall directly on the flats, is occurring at the rate of 45 mm per year (Baxter 1996). Saline groundwaters are rising by 9 cm per year on the valley flats and are within 1-2 m of the surface on the flats north of Dulbining Reserve (Baxter 1996). Groundwaters were recognised as being extremely saline (6,000 mS/m). Rates of groundwater rise had been measured near Toolibin Lake for over 17 years, at an average rate of 0.05 m/yr (George 1998).

In the National Airborne Geophysics report groundwaters were recognised to be near the surface in valleys (<2 m) and at greatest depth on hillsides. The study considered this relationship to be more likely in the east of the catchment (Zone of Ancient Drainage) but in the west, characterised by dissected landscapes, it was expected to be less consistent (George 1998). Information collected by the Toolibin Catchment Group suggested groundwaters occurred within 2-5 m of the surface throughout the eastern catchment (conductivities of 200-500 mS/m), although in the upper catchment, many dry holes had been drilled (<8 m; Negus, pers comm, 1985-1995). The lowest salt stores stores (<50 mS/m) were under ridges and on upper slopes while the highest stores (mean $EC_{1:5}$ >300 mS/m) were noted in lower slope areas (George 1998). George estimated that spatial patterns were likely to be gradational (changing) over 100 to 1000 m scales.

At paddock scale (<100 m) spatial patterns were noted to be influenced by local factors such as soil type and depth, slope position, and vegetation. It was estimated that by 1986, between 1.9 and 5.6 per cent of the catchment had become severely saline. This was based on landholders mapping; ABS surveys and data reported by Stokes and Martin (1986, op cit) (George 1998). CSIRO in 1996 calculated the area affected by salinity to be as high as 12 per cent based on Landsat TM analysis (George 1998). Ferdowsian *et al*. discuss studies that estimate the potential area of salt-affected land as 25-30 per cent of the catchment unless the landscape water balance is altered (George 1998). A palaeochannel was discovered on the eastern side of Toolibin Lake. In terms of management of the lake and wetlands the palaeochannel should have a significant impact. Drilling and groundwater pumping effects near the western shoreline would be increased by well placed drill-holes to de-water the palaeochannel. Toolibin has remained fresh when most wetlands around have become saline as a result of the palaeochannel. Airborne electromagnetics (AEM) and recent drilling now suggest that while the dykes may prevent inflow from the weathered-basement, the palaeochannel is the main source and escape mechanism for groundwater beneath the lake. Existence of the palaeochannel also explains an observation by Martin (1990) that the lake acted as a recharge area in winter and discharge area in summer. It now appears certain that the palaeochannel is the main geological feature responsible for natural drainage in summer (George 1998). In contrast to conceptual models defined in other studies the National Airborne Geophysics study found that features did not necessarily exert the same influence on salinity at both the farm and catchment scale. Drilling, magnetics and AEM suggested that at Toolibin, there was no unique or consistent role played by geological structures, and that only skilled interpretation and geophysical mapping appeared able to determine when such features as dolerite dykes were likely to be significant.

2.8 Salinity

All rain contains a very small amount of salt which over geological time amounts to large quantities deposited on the wheatbelt. Rainfall in the area is too low to leach the salt into the underlying watertable so it has accumulated in the soil profile (Halse 1988). Native vegetation transpires more water over a year than pastures and crops, primarily because of its perennial nature. The clearing of native vegetation reduces the use of soil water considerably and the watertable rises. Once a catchment has been cleared it can take 30 years for groundwater levels to stop rising (Halse 1988). As a result of the clearing that occurred in the 1930s to 1950s the watertable had risen 12 to 15 m and was within 1 to 2 m of the Toolibin Lake bed in 1988 (Halse 1988). By 1961 salt-affected pasture was evident immediately west of the lake (Casson 1987). Some records note salt encroachment on cleared areas as early as the 1930s, with 3 per cent of arable land severely affected (Casson 1987). Capillary rise causes salt to reach the surface when groundwater is within 1.5 m.

Salinity reduces or prevents plant growth and contributes to the salinity of surface run-off. It is estimated that 5.6 per cent of the valley flats in 1986 were affected due to evaporation of saline waters close to the surface (Baxter 1996). Landsat TM maps (c1996) indicated large areas (>12 per cent) were salt-affected (reduced cover) but interpretation by farmer surveys and field checking revealed that a smaller area (6 per cent) of the catchment was actually salt-affected (George 1998).

Shallow bores drilled in Scriveners Soak catchment (~1990) indicated that watertables were within 1 to 5 m across much of the valley area. These bores were monitored over several years and no trends in water levels were discovered. In the National Airborne Geophysics report preliminary time series analysis of bores suggests that saline watertables are rising (0.2-0.5 m/yr), and that significant salinisation is likely in the future (<150 years). Their prediction was approximately 24 per cent of the catchment at risk of shallow groundwater less than <1 m deep (George 1998).

2.9 Remnant vegetation

Remnant vegetation and roadside bush are estimated to cover 13 per cent of the catchment. Three per cent of remnant vegetation is contained in reserves managed by CALM, mostly around Toolibin Lake. Much of the remnant vegetation is unfenced and under great pressure from stock. Weeds and exotic animals are pressures faced by all remnant vegetation. Roadside vegetation is important in providing corridors for movement of animals and in 1991, 42 per cent was considered of high conservation value, 40 per cent medium and 18 per cent medium-low to low (Baxter 1996). A major concern for management authorities is that vegetation reserves near the lake and within creeklines are becoming salt-affected (Baxter 1996). The introduction of a catchment management plan in 1996 may have reduced some of these problems. Froend *et al*. (1987) details the natural vegetation of the catchment as heath and open woodlands of wandoo (*Eucalyptus wandoo*) and jam (*Acacia acuminata*) on the gravelly sands of the interfluves; woodlands of salmon gum (*E. salmonophloia*) and red morrel (*E. longicornis*) on the heavier valley soils; and York gum (*E. loxophleba*) on the sandier valley soils. Galleries of flooded gum (*E. rudis*) lined drainage lines, and wetlands supported dense thickets of sheoaks (*Casuarina* sp.) and bottlebrush (*Melaleuca* sp.

Most records detailing the plant communities concentrate on the vegetation near the lake. By 1993 26 families and 97 species had been recorded at vegetation monitoring plots established by Mattiske and Goodsell in 1977 (Mattiske 1993). Main plant communities defined by Mattiske include:

1. Woodland

Eucalyptus rudis (flooded gum)

E. loxophleba (York gum)

E. salmonophloia (salmon gum)

Casuarina obesa – Melaleuca strobophylla

2. Open Woodland

Eucalyptus rudis (flooded gum)

Casuarina obesa

E. salmonophloia (salmon gum)–*E. wandoo* (wandoo)

E. salmonophloia (salmon gum)

E. longicomis

3. Low Woodland

Casuarina obesa – Melaleuca strobophylla

Casuarina obesa

4. Low Open Forest

Banksia attenuata-B. menziesii - Allocasuarina huegeliana

5. Closed Scrub

Melaleuca lateriflora

6. Heath

Mixed closed heath of Myrtaceae–Proteaceae species

7. Herblands

Open herblands of Poaceae-Asteraceae species

8. Halophytic Complex

Halophytic Complex

Table 2.2: Main species identified in the Toolibin catchment (Mattiske 1993)

Family	Species	Family	Species
Poaceae	*Agrostis* sp.	Proteaceae	*Banksia attenuata*
	Aira caryophyllea		*Banksia prionotes*
	Aristida contorta		*Hakea lissocarpha*
	Avena fatua		*Hakea preissii*
	Briza maxima		*Hakea varia*
	Briza minor		*Hakea* sp.
	Bromus madritensis		*Dryandra* sp.
	Bromus sp.	Santalaceae	*Santalum murrayanum*
	Cenchrus sp.	Chenopodiaceae	*Halosarcia halocnemoides* var. *pergranulata*
	Danthonia sp.		*Halosarcia indica* ssp. *bidens*
	Hordeum geniculatum		*Halosarcia lepidosperma*
	Lolium perenne		*Sarcocornia quniqueflora*
	Neurachne alopecuroidea	Azioaceae	*Mesembryanthemum nodiflorum*
	Poa sp.	Portulaceae	*Calandrinia* spp.
	Polypogon monspeliensis	Caryophyllaceae	*Petrorhagia prolifera*
	Stipa elegantissima		*Spergularia arvensis*
	Stipa trichophylla		*Spergularia rubra*
	Stipa sp.	Brassicaceae	*Brassica tournefortii*
	Vulpia myuros	Mimosaceae	*Acacia acuminata*
	Vulpia sp.		*Acacia erinacea*
Cyperaceae	*Chorizandra enodis*		*Acacia leptopetala*
	Gahnia ancistrophylla		*Acacia microbotrya*
	Gahnia trifida		*Acacia pulchella*
	Lepidosperma angustatum	Papilionaceae	*Daviesia horrida*
	Lepidosperma pubisquameum		*Gompholobium tomentosum*
	Lepidosperma tenue		*Jacksonia furcellata*
Restionaceae	*Lepidobolus preissianus*		*Templetonia sulcata*
	Leptocarpus sp.		*Trifolium angustifolium*
	Lyginia barbata		*Trofolium* spp.
Dasypogonaceae	*Lomandra effusa*	Geraniaceae	*Pelargonium havlasae*
	Lomadra rupestris	Lineaceae	*Linum marginale*
Phormiaceae	*Dianella revoluta*	Myrtaceae	*Calytrix brachyphylla*
Casuarinaceae	*Allocasuarina huegeliana*		*Eremea pauciflora*
	Casuarina obesa		*Eucalyptus loxophleba*
			Eucalyptus longicornis

Table 2.2: Main species identified in the Toolibin catchment (continued)

Family	Species	Family	Species
Myrtaceae	*Eucalyptus rudis*	Thymelaeaceae	*Pimelea argentea*
	Eucalyptus salmonophloia	Apiaceae	*Apium* sp.
	Eucalyptus wandoo	Primulaceae	*Anagallis arvensis*
	Eucalyptus sp.	Convolvulaceae	*Wilsonia rotundifolia*
	Kunzea preissiana	Goodeniaceae	*Goodenia* sp.
	Melaleuca acuminata	Asteraceae	*Cotula* sp.
	Melaleuca lateriflora		*Gnaphalium* sp.
	Melaleuca strobophylla		*Helichrysum* sp.
	Melaleuca uncinata		*Helipterum* sp.
	Melaleuca viminea		*Hypochaeris glabra*
	Melaleuca sp.		*Podotheca* sp.
	Pericalymma ellipticum		*Senecio lautus*
Sapindaceae	*Dodonaea viscosa*		*Ursinia anthemoides*
Rhamnaceae	*Cryptandra pungens*		*Waitzia acuminata*
			Waitzia sp.

Hopkins (pers. comm.) recorded mallee in the catchment, referring to a form of tree rather than specific species. Mallees are multi-stemmed from the ground, usually less than 10 m in height, often with the crown predominantly at the ends of the branchlets. Individuals may combine to form an open or closed formation (Williams and Brooker 1997). Mallet, which was recorded as part of the historical surveys, is also a growth form and describes a smooth-barked, small to medium-sized tree, that normally has a steep branching habit, is sometimes fluted at the base of the trunk, and often has a conspicuously dense, terminal crown (Williams and Brooker 1997).

2.10 Flooding, waterlogging and erosion

Waterlogging is a common problem t occurring every one to two years and affecting up to 30 per cent of the crop in any one year. This can be considerably higher in wet years and affects pastures as well. Flooding is known to occur on the flats one in five years. Wind erosion is particularly bad on the deep sands in the upper catchment and occurs on most soil types (Baxter 1996).

3. Methodology

Methodology comprised the following steps:

1) Scanning of aerial stereo photographs;
2) Geo-referencing images;
3) Production of the digital mosaic and accuracy measure;
4) Digitising, cleaning and attributing of remnant vegetation for 1962, 1972, 1983 and 1996;
5) Digitising and attributing of historical information from chain maps;
6) Building the database;
7) Exploration and initial spatial analysis; and
8) Rasterising layers, continued spatial analysis.

These steps and the software packages used are detailed in Figure 3.1.

3.1 Production of digital mosaics using multi-temporal aerial photographs

Aerial photographs from 1962, 1972 and 1983 were obtained for the Toolibin catchment and scanned to produce multi-temporal digital mosaics. An outline of this process is presented in Figure 3.2. A uniform pixel resolution of 2 m was set, and therefore different scanning resolutions were adopted (Table 3.1).

Table 3.1: Scanning resolution as a function of photo-scale

Year	Photo scale	Scanning resolution	Output pixel size
1962	1:40,000	600 dpi	1.68 m
1972	1:40,000	600 dpi	1.68 m
1983	1:50,000	650 dpi	1.95 m

Digital orthophotos from 1996, generated at a resolution of 1.2 m by DOLA were used as the 'master images' for rectifying the aerial photographs. Evenly distributed ground control points were selected from the orthophotos and digital vector files containing cadastral information. The latter were helpful to select control points in areas of scarce development (e.g. absence of roads) and where the land cover had changed remarkably over time. A minimum of nine control points distributed along the edges and centre of each photo were chosen, as this was necessary to ensure that the mapping polynomials produced an accurate result over the entire image. Second and third order transformation models can produce rectified images with distortions more complex than the original image. While the higher order polynomials will be accurate near the control points themselves, they can lead to significant errors, and thus image distortions for portions of the image outside the range of the control points (Richards 1986). Because an even distribution of control points was difficult to achieve in some areas, particularly along the catchment boundary and in the older aerial photographs, a first order polynomial transformation (i.e. affine) was selected.

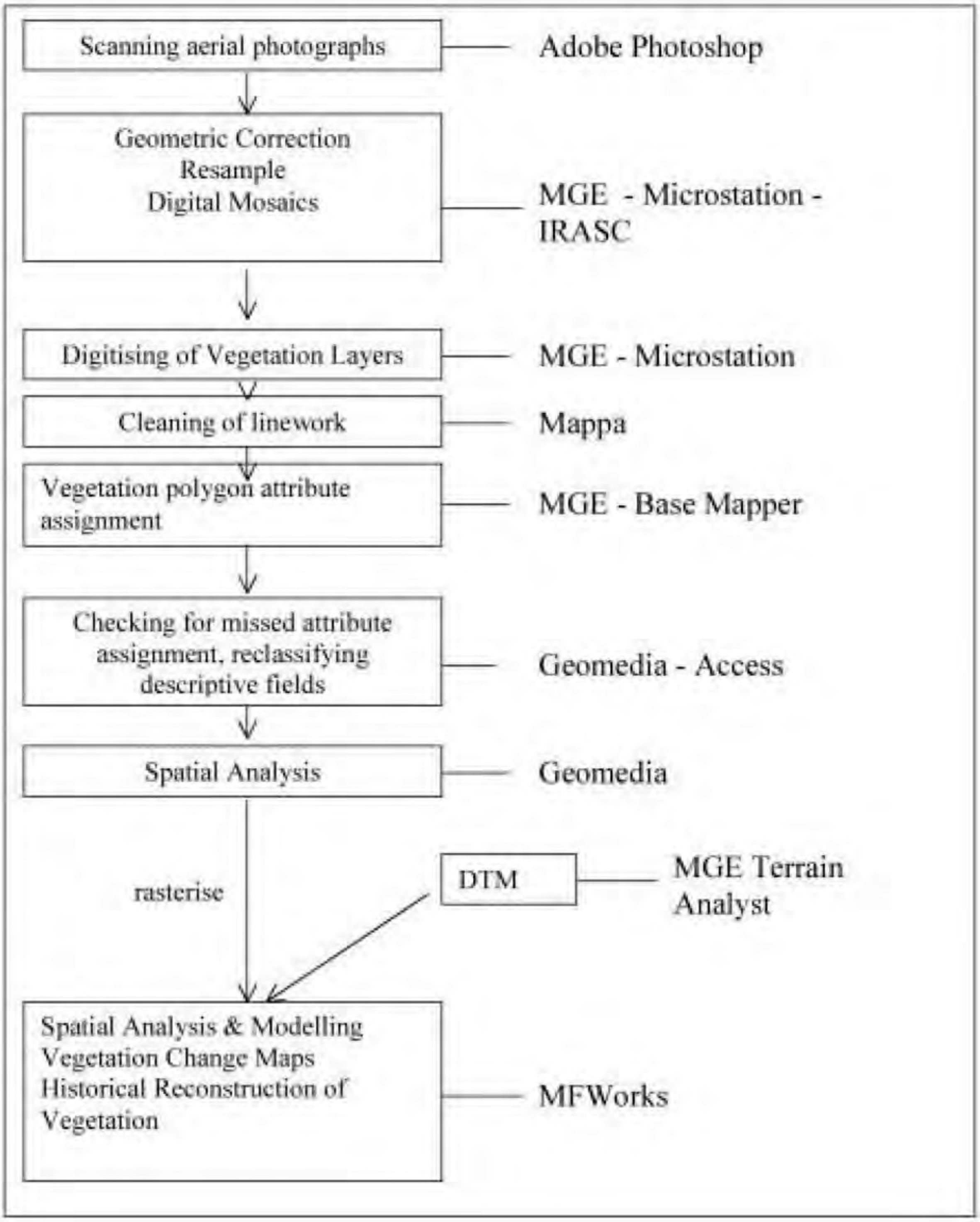


Figure 3.1: Methodology outline and software packages used

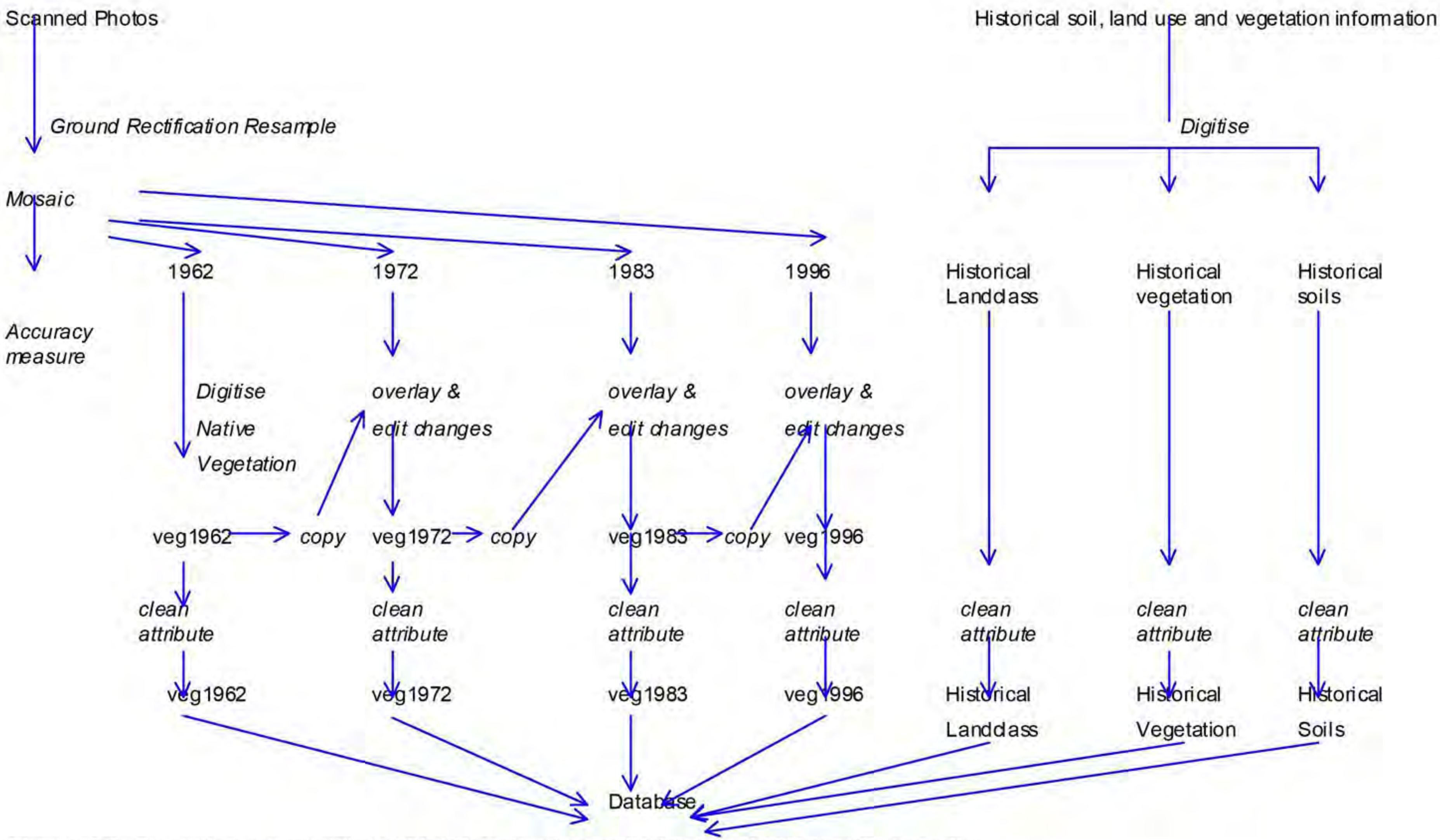


Figure 3.2: Flow diagram showing initial Construction of Database (MGE and Geomedia)

The X and Y residuals, representing the differences between actual coordinates of the warped input points and those calculated through a least square adjustment, were used to calculate the sum of the squared error (SSE) for each point in the model (Figure 3.3). In order to keep the standard error within the pre-determined limit of less than 3 m (or 1.5 pixels), points with the greatest SSE were replaced or omitted, while still trying to retain an even point distribution (see Appendix 6, Tables 6.1 to 6.3,). Bilinear interpolation was chosen to resample the warped photographs to a 2 m pixel size. The rectified photographs were then integrated to produce a digital mosaic for each year (e.g. 1962, 1972 and 1983). Strips of adjacent images were generated first. These 'runs' were then merged into blocks to derive the complete digital mosaic. A join seam following land boundaries and avoiding crossing vegetation patches, wherever it was possible, was selected.

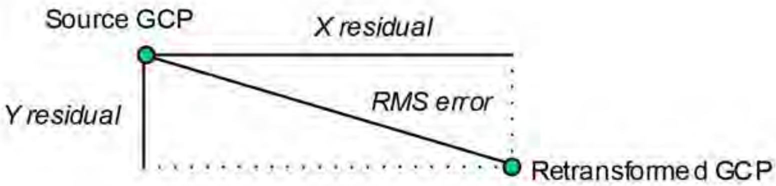


Figure 3.3: Relationship between the residuals and the root mean square error per point

3.2 Quality control

Check plots were computed in the digital mosaics in order to determine the positional accuracy of spatial data. To this end, manual verifications were undertaken by selecting 74 points and reading their coordinates in the digital orthophoto produced by DOLA, and the mosaics. The total root mean square error (RMSE) was then determined for each mosaic using equations 1, 2 and 3:

$$Rx=\sqrt{\frac{1}{n}\sum_{i=1}^{n} XR_i^2}$$

$$Ry=\sqrt{\frac{1}{n}\sum_{i=1}^{n} YR_i^2}$$

$$T=\sqrt{\frac{1}{n}\sum_{i=1}^{n} XR_i^2+YR_i^2}$$

where

Rx and *Ry* represent the RMS error in X and Y respectively;

T is the total RMS error for a mosaic; *n* is the number of check points selected;

i is the GCP number; and

XR_i and YR_i are the X and Y residuals for GCP_i

Root-mean-square errors of 0.85 m and up to 18 m were computed for the 1962, 1972 and 1983 mosaics. The coordinates of the check points were plotted to determine the presence of systematic patterns in the shift of data with respect to the 'true' position as determined from the 1997 orthophotos, and also to determine the evenness in the distribution of errors over the mosaics. The rectified mosaics showed a non-uniform shifting. For instance, a shift of 10 m south-west was detected in some check points located in the top left part of the mosaic, while features in the top right may have appeared 15 m north from their 'true' position.

3.3 Extracting multi-temporal native vegetation and revegetated areas

Several practical decisions had to be undertaken at this stage. Remnant patches of native forest corresponding to 1962 were digitised first. Isolated trees were included in a patch of remnant vegetation if they were within a crown separation ratio lower than 20. Clumps were defined for groups of three or more trees. Some areas on the digital mosaic were not very clear, as the scanning and mosaic processes resulted in very dark patches. Sometimes it was necessary to refer to the original photo and determine the boundary of remnant patches by stereoscopy. The digital conversion of the hardprints also produced a loss of image clarity, making some patches of arable land or waterlogged areas resemble native vegetation. This necessitated checking against the original photographs.

To reduce time, the digital file corresponding to remnant patches of 1962 was duplicated, and used with the digital mosaic of 1972 to extract the patches of remnant vegetation present in 1972. In other words, the digital vector file of 1962 was overlaid on the 1972 digital mosaic and each patch was then examined to find whether it still existed in 1972 and to what degree its shape was modified. During this stage the problem of misalignment of objects in the different multi-temporal coverage became evident, and resolved by conflating the polygons to the same coordinates as the base coverage.

Although the aerial photographs were geo-referenced using a polynomial transformation, specific distortions due to crabbing and yawing of the aircraft, or relief, are not eliminated in this process. Thus, not all the internal objects present in the digital mosaic will be accurately represented and their spatial location may vary from one mosaic to another. In this instance, no analysis of area change will be valid if the polygons themselves don't line up. Objects that are in the correct place need to be 'tacked down', while moving the remainder to more accurately indicate their locations in space. Such is the process of conflation, whereby an interactive process that involves deciding which of the coverages will be adjusted with respect to the other, so that polygons will coincide. Sometimes the entire coverage is adjusted, but most often this approach produces unwanted distortions of objects that were originally representative of correct locations and correct shapes (De Mers 2000).

Therefore, time was spent identifying individual polygons that needed to be conflated. This required copying and moving some of the complex boundary shapes of remnant patches to their corresponding patch, as represented in the digital mosaic displayed as the background image. In this way it could be verified whether or not changes in the shape of a patch did occur over the time considered (e.g. 1962-1972, 1972-1983 or 1983-1997). If the shape of the boundary differed by more than one or two 'trees', the patch was edited to fit the shape to the current situation. This procedure is illustrated in Figures 3.4*a* to 3.4*d*. The green line is the original 1962 linework. Figures 3.4*a* and 3.4*b* represent the process of copying and placing original linework in the 'correct position' in relation to the 1972 vegetation cover. Figure 3.4*b* shows that the shape of the bottom line fits the 1972 vegetation and therefore modifications are not needed. However, the top line is obviously different, and was edited and re-digitised to reflect the 1972 situation (Figure 3.4*c*). Once this process is completed, the linework corresponding to 1962 is deleted and replaced with the newly digitised top boundary (ie. the 1972 remnant patch). The modified polygon shape is then moved into its original position so that when analysing multi-temporal changes, a reliable estimate can be obtained (Figure 3.4*d*). Figures 3.5*a* to 3.5*g* show this problem over a larger patch, where the shift is not uniform. Overall, this was a long time-consuming process intended to resolve the problem of working with historical aerial photographs, when more accurate datasets such as orthophotos did not exist.

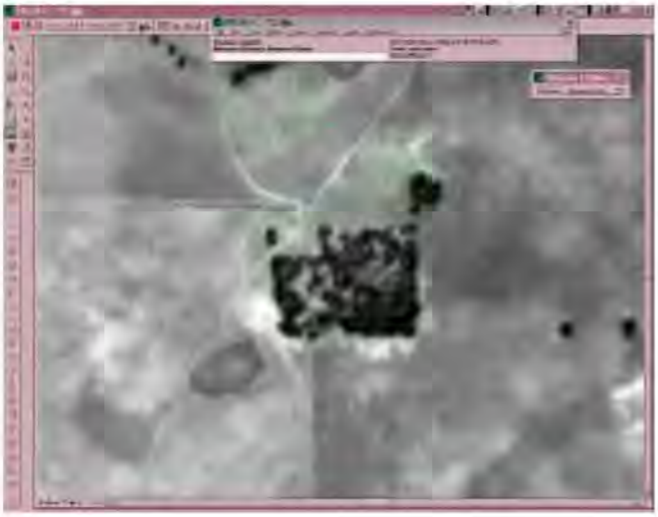


Figure 3.4a: 1972 mosaic displayed as a background image, with the 1962 digitised remnant vegetation as foreground

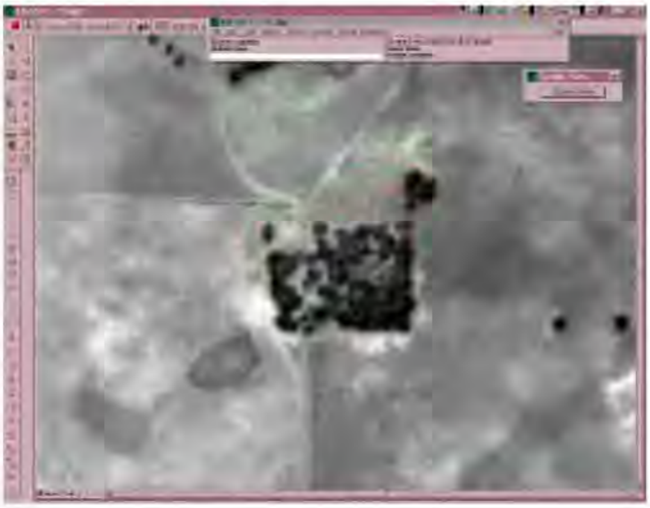


Figure 3.4b: 1962 linework copied and moved to coincide with its representation in the 1972 digital mosaic, in order to evaluate the magnitude of changes

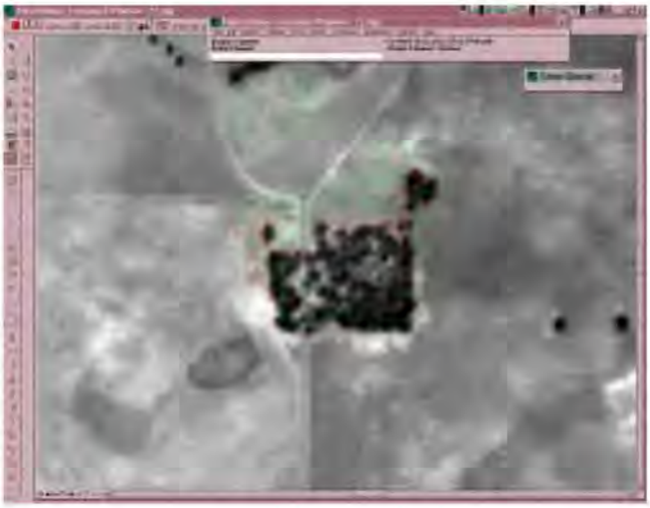


Figure 3.4c: The polygon is edited to digitise the new boundary

Figure 3.4d: The polygon reflecting the true shape of the remnant patch for 1972 is moved to its original position so that reliable changes are detected when the coverages are overlaid

New patches of native vegetation that were not present in the 1962 digital mosaic, were digitised and a relative location with respect to patches already digitised, was determined. This procedure was repeated for generating the 1983 coverage of native vegetation. Likewise, the 1996 coverage provided by the Department of Agriculture was compared against the work produced in this project. This procedure was needed to ensure that polygons representing the same patches of remnant vegetation coincide, and that multi-temporal analysis of changes reflects only true changes due to forest clearance or revegetation.

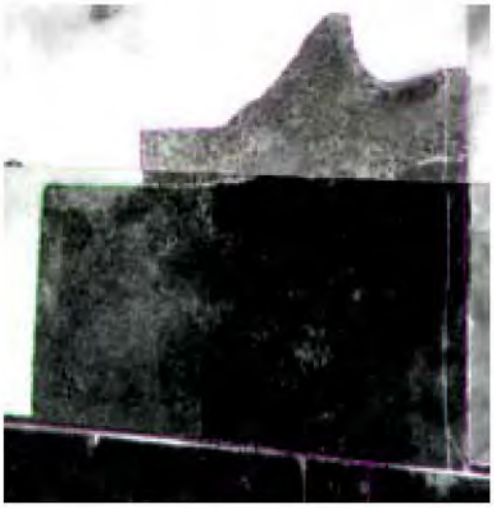
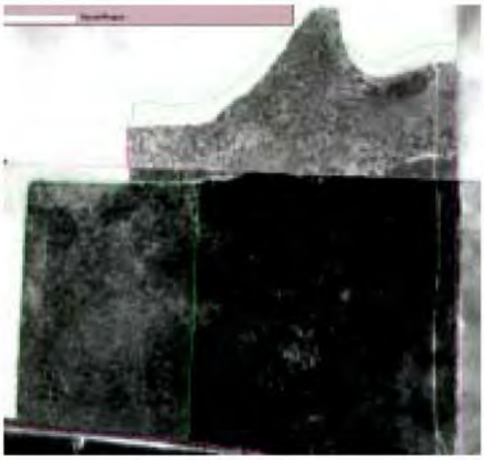



Figure 3.5a: Original 1962 linework with mosaic Figure 3.5b Adjusted 1962 linework.

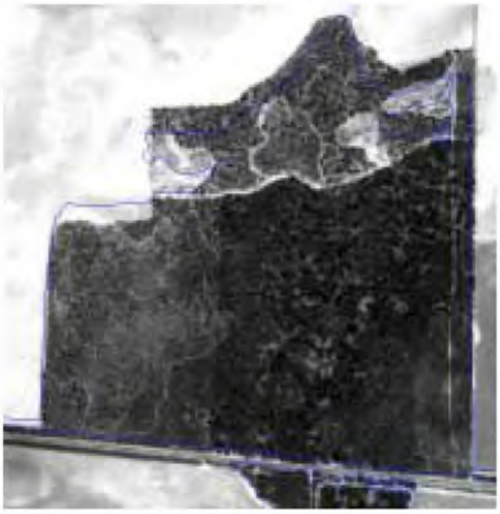
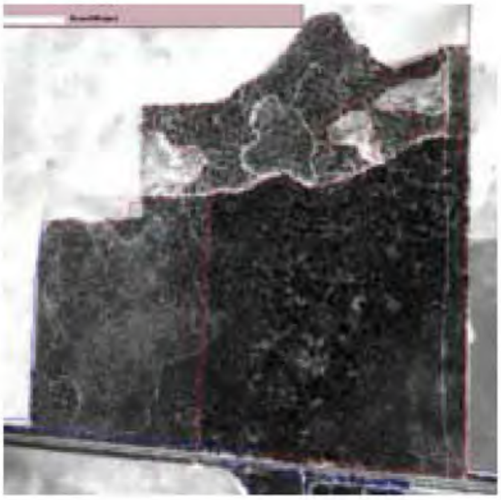



Figure 3.5c: Original 1972 linework with 1972 mosaic Figure 3.5d: Adjusted 1972 linework

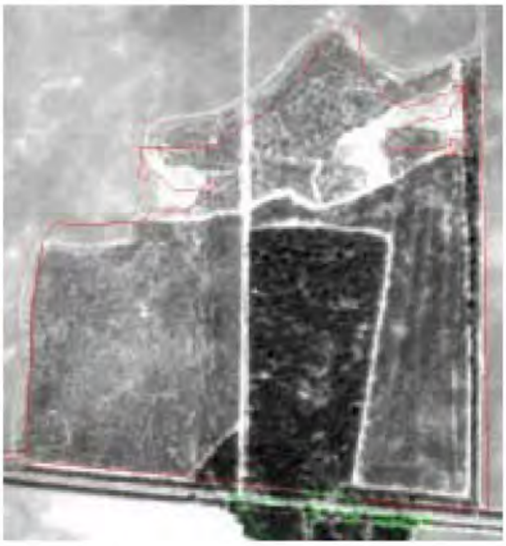
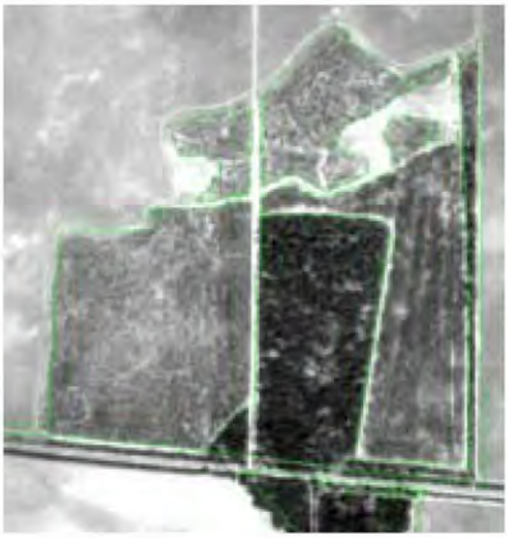



Figure 3.5e: Original 1983 linework with 1983 mosaic Figure 3.5f: Adjusted 1983 linework

Figure 3.5g: How the linework of 1962 (pink), 1972 (blue), 1983 (red), with 1972 mosaic as the image, fits together

3.4 Development of vegetation layers

Once the digitising of the temporal layers of vegetation was complete, the linework was cleaned (using Mappa) and coded, with each layer assigned a unique feature (centroid and boundary feature for each polygon) and associated with only one feature table. The clean layers were complexed so the polygon acted as a complete unit rather than two separate features. Vegetation class attribution commenced with the 1996 layer, using the displayed mosaic in conjunction with the aerial photographs. The 1996 layer was completed first, as it was the one that could be best estimated from a combination of stereo-photo-interpretation and fieldwork undertaken during 1999 by SPIRT team collaborators (Hopkins and Gonzales). Information gathered in the field was extrapolated to the rest of the catchment applying the interpretation keys commonly employed for aerial photographs (e.g. tone, texture, shape, size and pattern). Sometimes this involved additional interpretation of stereo pairs of aerial photographs. The 1996 aerial photographs were at scale 1:25,000. The vegetation classes developed for this project are detailed in Table 3.2.

A very detailed survey of vegetation condition, species in the stratums, general descriptions of the patches and emergents was done in one strip of the catchment area by Hopkins. The area is presented in Figure 3.6 and the results are summarised in Appendix 1.

The only means of interpreting vegetation attributes for the layers representing years 1962, 1972, 1983, 1996 was by photo-interpretation of the stereo pairs, and transferring the attributes assigned to the same plot in 1996. It was assumed that unless the appearance of the remnant changed drastically, the 1996 vegetation class could be transferred to the earlier layer. Any remnants that didn't exist in 1996 (i.e. cleared) had to be classified based on their appearance in the current black and white mosaic. If this was unclear the aerial photographs were stereo-interpreted to determine a vegetation class. As done in 1996, 'new' remnants in earlier years were assigned the same attribute provided it wasn't significantly different. Bare areas within a vegetation polygon were given a class value of 13. Another problem arose when the area in the 1996 aerial photographs was subdivided differently to the digital version or when an area that existed in more than one temporal layer, was subdivided differently between layers. A decision was made to allocate the class that corresponded to the greatest area. For instance, a remnant may be divided into four different classes in the 1996 digital mosaic, being digitised as one area – the largest of the four areas is allocated to the entire polygon. Once this class was allocated it carried down through preceding layers. Due to the black and white nature of the aerial photographs from 1983, 1972 and 1962, differentiating between crops and native vegetation was sometimes difficult.

Table 3.2: Vegetation classes developed for mapping native forest

Class	*Height*	*Density*
1	Tall trees with understorey vegetation	Sparse
2	Taller trees without understorey vegetation	Sparse
3	Tall trees mixed with lower vegetation	Tall trees very sparse
4	Dominant low trees, few tall ones	Dense
5	Dominant low trees, few tall	Mid-dense
6	Tall trees	Very sparse (2-20 trees of separation)
7	Low vegetation (bushland)	Very dense
8	Very tall trees with low vegetation very dense	Low vegetation very dense
9	Low vegetation	Closed or dense (very dense)
10	Revegetated areas	
11	Tall trees	Very dense
13	Island polygons without vegetation	

Note: A polygon consists of one outer ring and possible inner rings. A simple polygon has no inner rings; a complex polygon has one or more inner rings, called 'holes' or 'islands'. These islands can represent different class types to the surrounding polygon or an absence of any class (cleared area).

3.5 Historical layers

The historical records were derived from surveys (Classification and Valuation Forms) provided by the Department of Agriculture. The forms contained various data detailed in Figure 3.7. Not all fields on the form were complete and not all maps included soil, vegetation and land use information.

The maps (an example is shown in Figure 3.7) were digitised resulting in three historical layers: land use; vegetation; and soil with associated databases containing the non-graphical information. Some areas had multiple surveys. Three hundred and twenty land use records, 11 soil and 48 vegetation records were digitised and their attributes integrated into the final historical vegetation, soil and land use databases. The land use records cover about 14,137 hectares. Not all is located within the catchment boundary, some areas fall completely outside, the furthest being 1.5 km north-east. Most records are from the east of the catchment (Figure 3.8). Not all the land use records describe vegetation, therefore the vegetation layer derived from land use, only covers 9,685 hectares (Figure 3.9). The historical soil records only cover 472 hectares (Figure 3.10), with four areas in the east and the rest in the west. The historical vegetation records cover 937 hectares and are mainly small areas around the edges of the catchment (Figure 3.11).

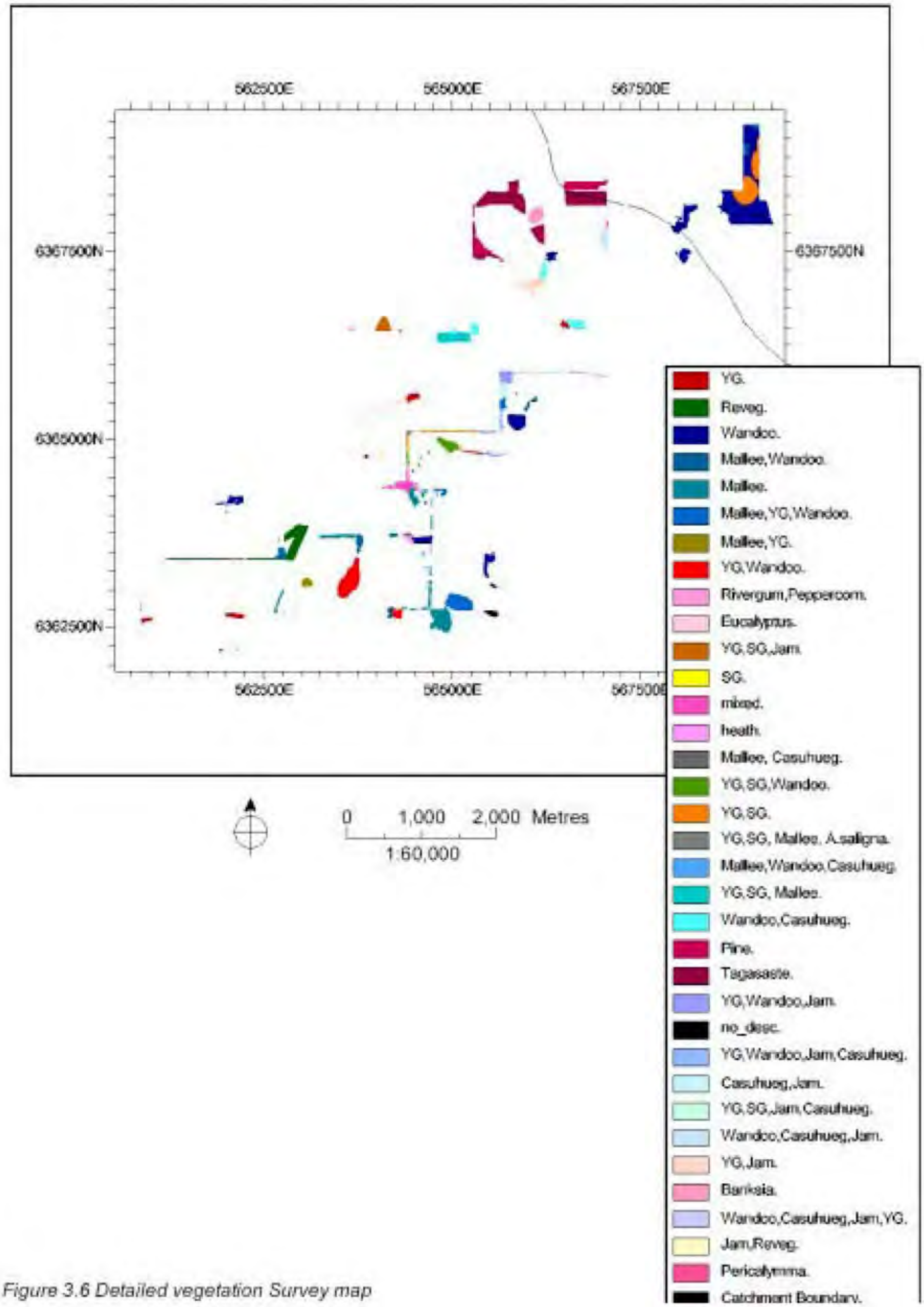


Figure 3.6 Detailed vegetation Survey map

Note: Abbreviations are explained in Table 6.4

- District, location number, area, plan number
- Railway Siding and distance from the railway
- Land use –a map of the area and description (sample on left)
- Estimated yield per acre of wheats, oats etc
- Estimated number of acres per sheep
- Present market value per acre on C.P. (Conditions of Payment)
- Cost per acre of ring barking
- Cost per acre of scrub cutting
- Cost per acre of clearing when timber is dead
- Value, position and nature of improvements (if any) and by whom effected

Figure 3.7 Example of an historical survey map and the information that could be contained

3.6 Data processing

The data layers were visually explored in Geomedia. A new Geomedia workspace was created and connections established to the different databases (*Warehouses> New Connection*>select type of connection e.g. Access, MGE and give connection a name). Figure 3.12 illustrates this process. The features could be added to the map window for display by choosing '*add feature class*' and selecting the connection in which it resides.

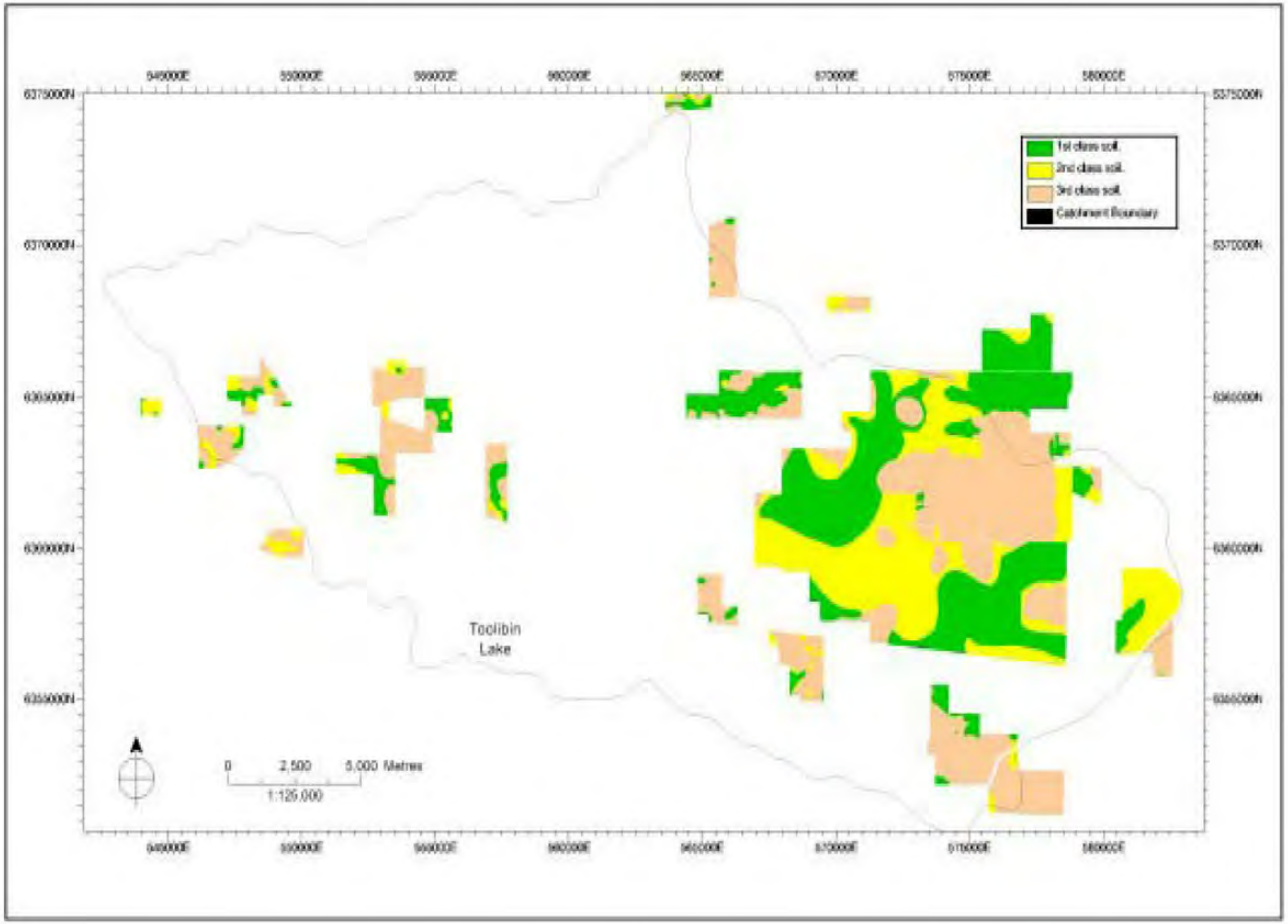


Figure 3.8: Historical land use records (reclassed to three soil classes)

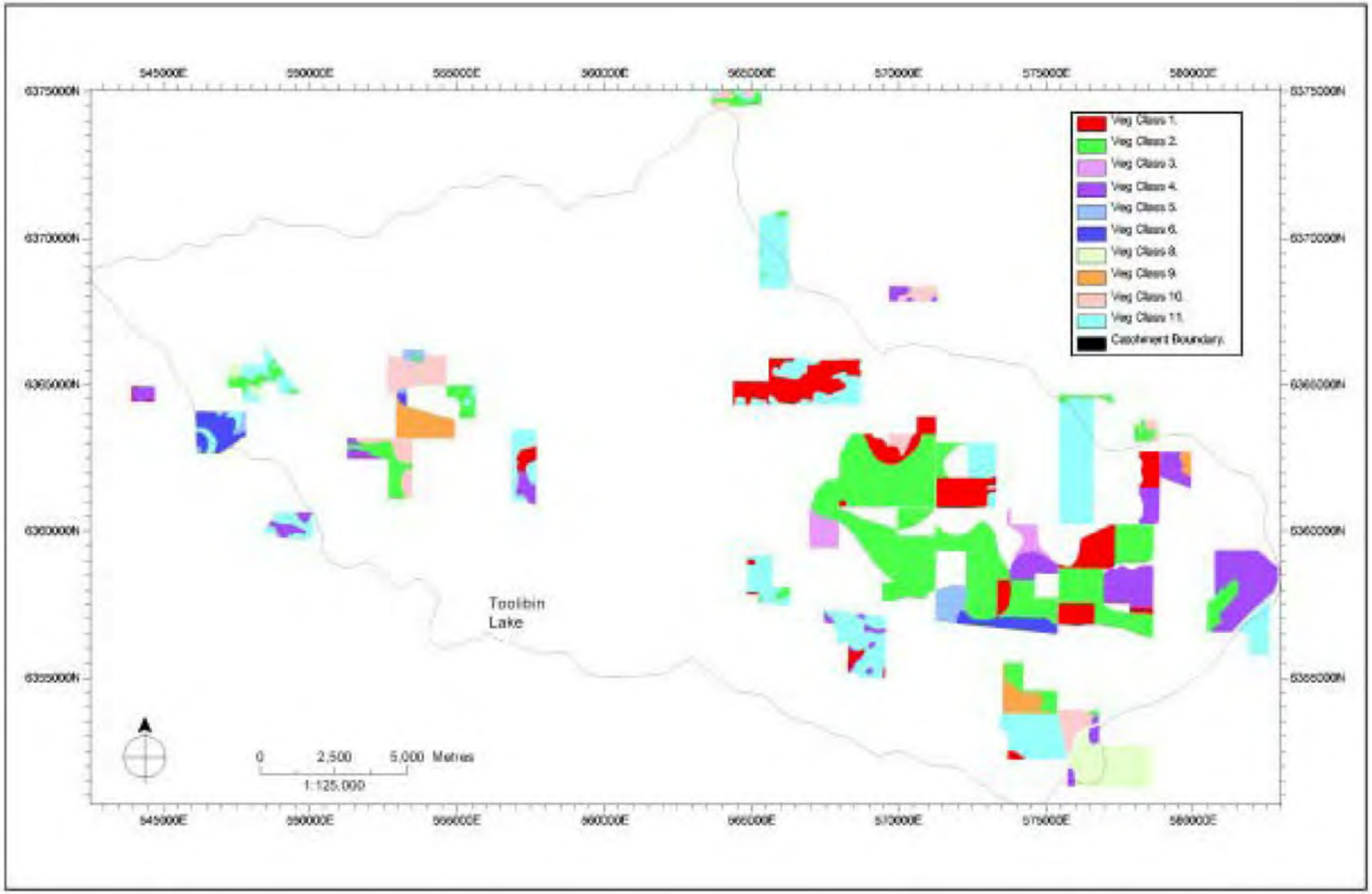


Figure 3.9: Historical land use records (vegetation 11 classes)

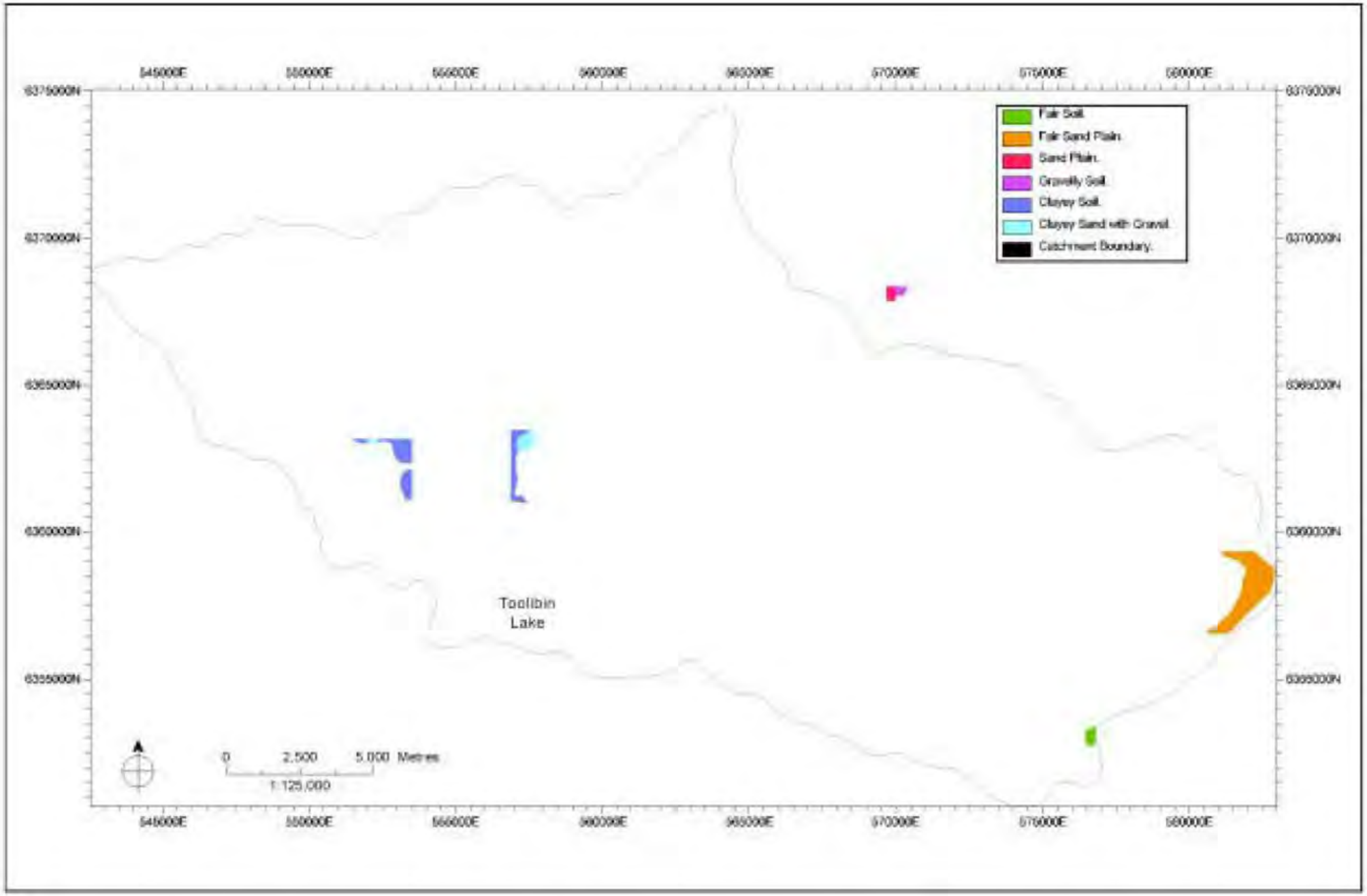


Figure 3.10: Historical soil records (six classes)

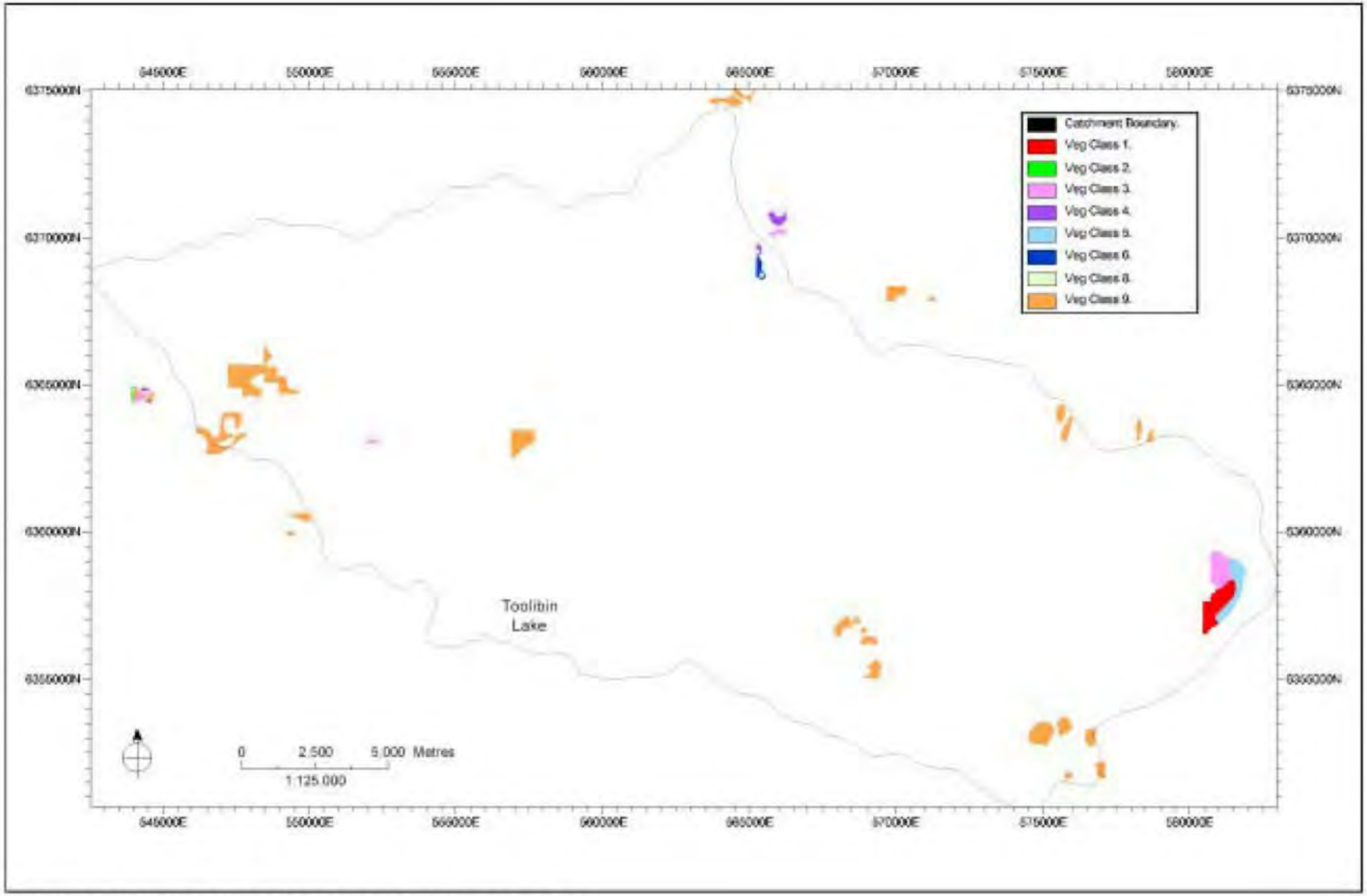


Figure 3.11: Historical vegetation records (11 classes)

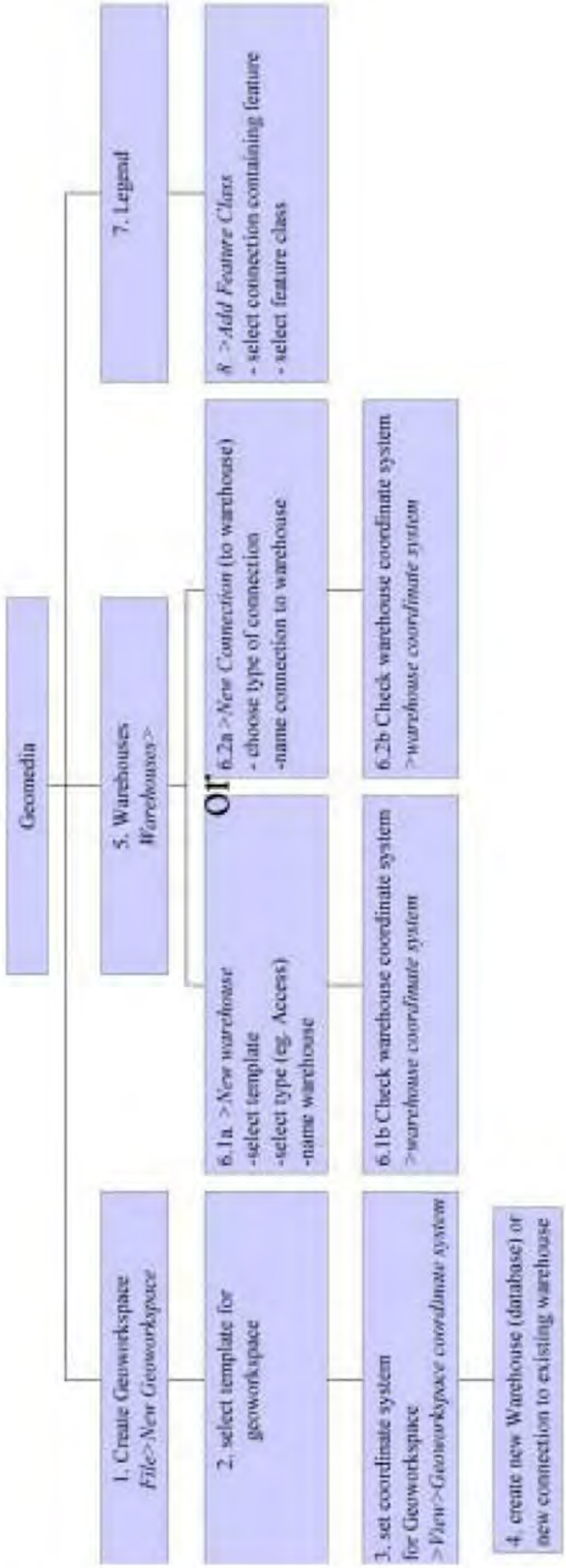


Figure 3.12: Workflow for setting up Geomedia connection to database and how to add features to the map window (commands shown in italics)

3.7 Vegetation layers (1962-1996)

Geomedia's tools for examining geometrical anomalies were run and the suspect areas examined individually and corrected if appropriate. Sliver polygons were identified and corrected at this time. Queries were run to determine if any of the polygons lacked attributes and any omittances rectified. Initial spatial difference operations were performed to see if Geomedia would be suitable for generating the multi-temporal vegetation change. Tables of the digitised remnant patches of vegetation were extracted showing the number of remnants, area and percentages for each year (Tables 4.1 to 4.4). These will be discussed in Section 4.1.

3.8 Historical layers

At this stage the historical data was not classified. Figure 3.13 shows the flow diagram of the classification process. The historical land use layer (hereafter referred to as *landclass*) had two main fields of interest, soil type (soil identification) and timber. New attribute fields were added to the table in MGE and populated in Access with the classified values.

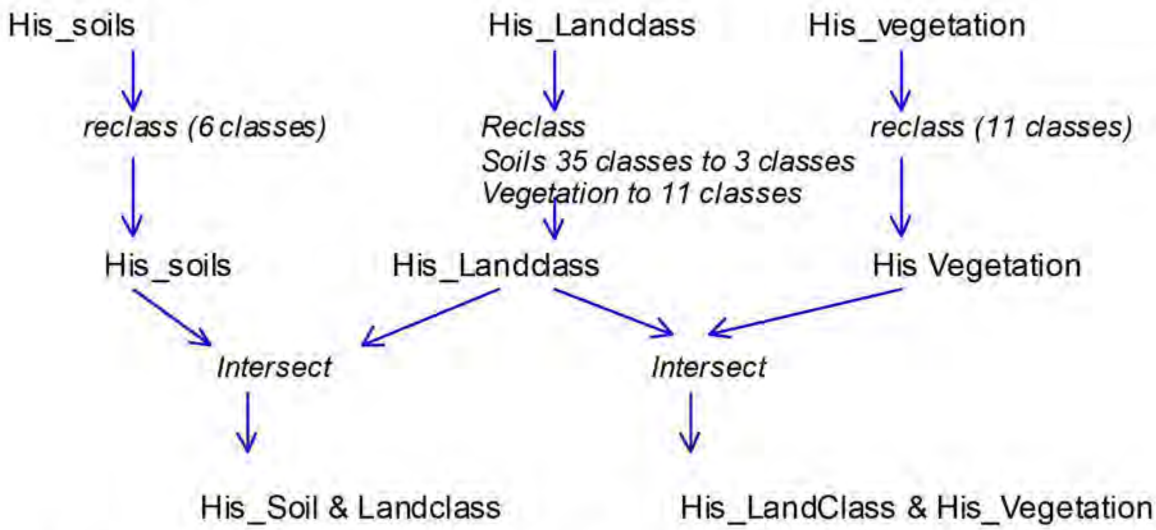
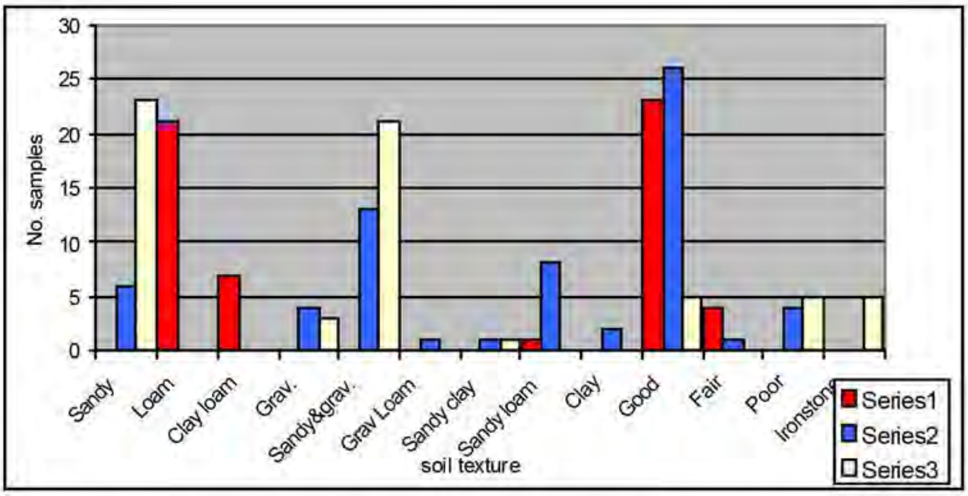


Figure 3.13: Flow diagram for the reclassification and checking of historical layers

The *landclass* data initially had 35 soil classes that were reduced to three using soil texture description to group records. An analysis was carried out to determine the dominant texture in these three soil types. A total of 81 polygons digitised within the catchment were labelled as first class, 94 as second class and 69 as third class. The soil texture and dominance of 'poor', 'fair' or 'good soils' are as Figure 3.14.



Series 1: 1st class soils; series 2: 2nd class soils, and series 3: 3rd class soils
Source: his_landclass (cleaned soil data worksheet)

Figure 3.14: Chart of relationship between soil texture and soil type

First class soils are characterised by loamy and clay loam textures, or described as good to fair soils in the mallet maps. Second class soils are characterised by a larger variety of textures, and general descriptions of good and fair soil types. Sandy and gravelly, sandy loam, and sandy textures predominate, with gravelly, gravelly loam, sandy clay, and clayey soils to a lesser extent. Third class soils are of poor quality, with ironstones present in several units. Sandy and sandy and gravelly textures are predominant, with less gravelly and sandy clayey soil textures.

Several polygons lacked soil descriptions, with a total of 23 for first class soils, 25 for second and five labelled as third class soils.

The soil units mapped in the rest of the area presented sandy (i.e. sandplain) textures, with fair soils and sandy clayey textures to a lesser extent.

The historical vegetation layer and timber in the *landclass* layer had a vegetation description, which was classified into 11 classes (Table 3.3). Of the initial 320 records in the *landclass* database, only 220 had vegetation information that could be classified.

Spatial analysis of the *landclass* layer showed overlapping among some polygons, as a result of multiple surveys from different times. These were examined and the decision made to exclude the records from 1944 (eight records) which coexisted with 1923, and eight records from 1912 which coexisted with 1919 records. The 1944 was excluded as there were only a small number, and 1912 because 1919 and 1923 were closer in time and it was thought those records would better describe the land use. The problem of overlapping polygons arose in the historical vegetation layer, where one polygon overlapped two others and was almost fully represented by the other two. As this was the case, the single polygon was excluded.

Table 3.3: Classification of vegetation in *landclass* and historical layers

Class code	*Class name*	*Composition*
1	Morrel/morrel and mixed woodland	Morrel, salmon gum, mallee (dominance of trees associated with 1st class soils)
2	Salmon gum/ salmon gum and mixed woodland	Salmon gum, jam (dominance of trees associated with 1st class soils)
3	Wandoo	Wandoo, small wandoo
4	Wandoo and mixed woodland	Wandoo, mallee, mallet (dominance of trees associated with 2nd class soils) wandoo, morrel, mallet
5	Mallet and mixed woodland	Mallet, mallee, wandoo, stony poison
6	Mallee/ mallee and mixed woodland	Mallee, wandoo, sheoak, sandplain, box poison (trees associated with 2nd class soils)
7	Mallee and mallet	
8	Sheoak/sheoak and mallee	
9	Native shrubs poisonous	Box and prickly poison, York Road poison
10	Scrubland	Blackboys, scrub
11	Scrub and mixed woodland	Mallee and scrub, box poison

Initial visual comparison of the Historical data in Geomedia showed that the vegetation information in the Historical Vegetation layer didn't cover any new areas that were not already represented in the historical *landclass* layer. In order to obtain maximum information for the areas where an overlap between the layers occurred the layers were combined so the attributes of both were available in one table. This required a union operation, functionality missing from Geomedia. To obtain the desired output a three-stage process (see Figure 3.15) was followed:

1. Perform a *spatial intersection* (*spatial tools*> select *create feature class*) on the historical *landclass* and the historical vegetation layers, choose method of intersection as overlap.

2. Perform a *spatial difference* (*spatial tools*>, select *create feature class*) between Historical *landclass* and historical vegetation – as we knew that historical vegetation did not exist in any location independent of *landclass* only the one difference operation was needed.

3. In Access (using an *append query*) add the records from the spatial difference feature to the intersection feature records.

Visual examination of the *landclass* soil and the historical soil layers showed that the *landclass* soils fully represented all the soil information available from the two layers. As few records existed in the historical soil layer and the attributes would add no further useful information, the *landclass* soils were used for analysis and mapping.

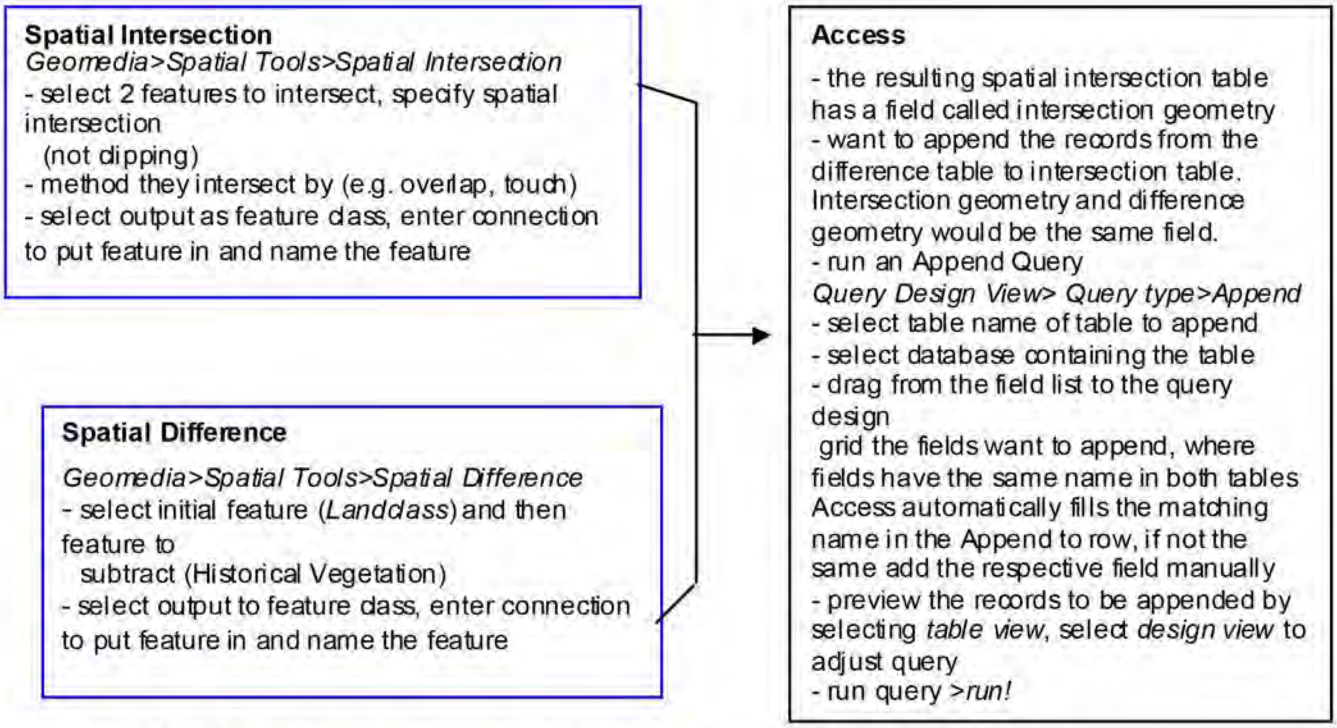


Figure 3.15: Process for generating a union using Geomedia and Access

3.9 Reconstructing a historical soil map

To model the entire catchment area's historical soils, the current soil data were reclassified based on the historical soil data classification (process in Figure 3.16). A spatial intersection between current soil data and the *landclass* data was performed (Figure3.17). The frequencies of the intersecting areas were recorded. Initially it was thought to use frequency alone to determine which historical soil class the current soil classes were best represented by, but as many had equal frequencies the areas were included as well. On examination it seemed more logical to use the area intersection to determine the historical soil classification. The current soil data were reclassified into the three historical soil classes. Some of the original soil classes didn't intersect with the *landclass* soil units, thus a number of classes were assigned a value of zero in the reclassification. The interpolated layer, termed the 'reconstructed soil map', is presented in Figure 3.18.

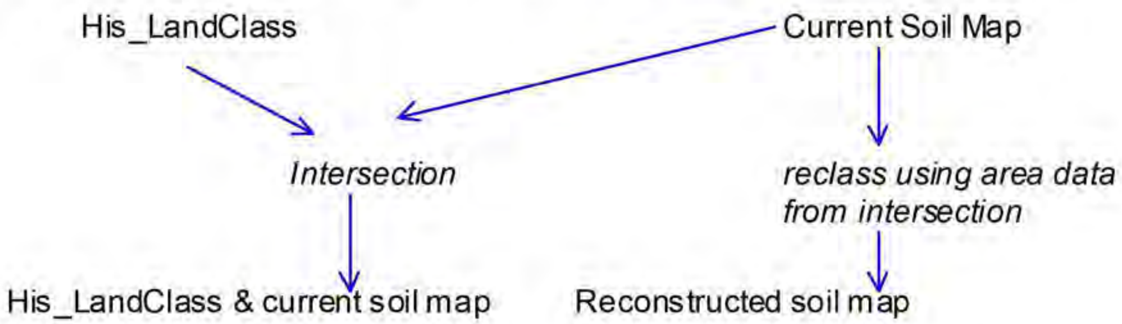


Figure 3.16: Flow diagram for the production of the reconstructed soil map

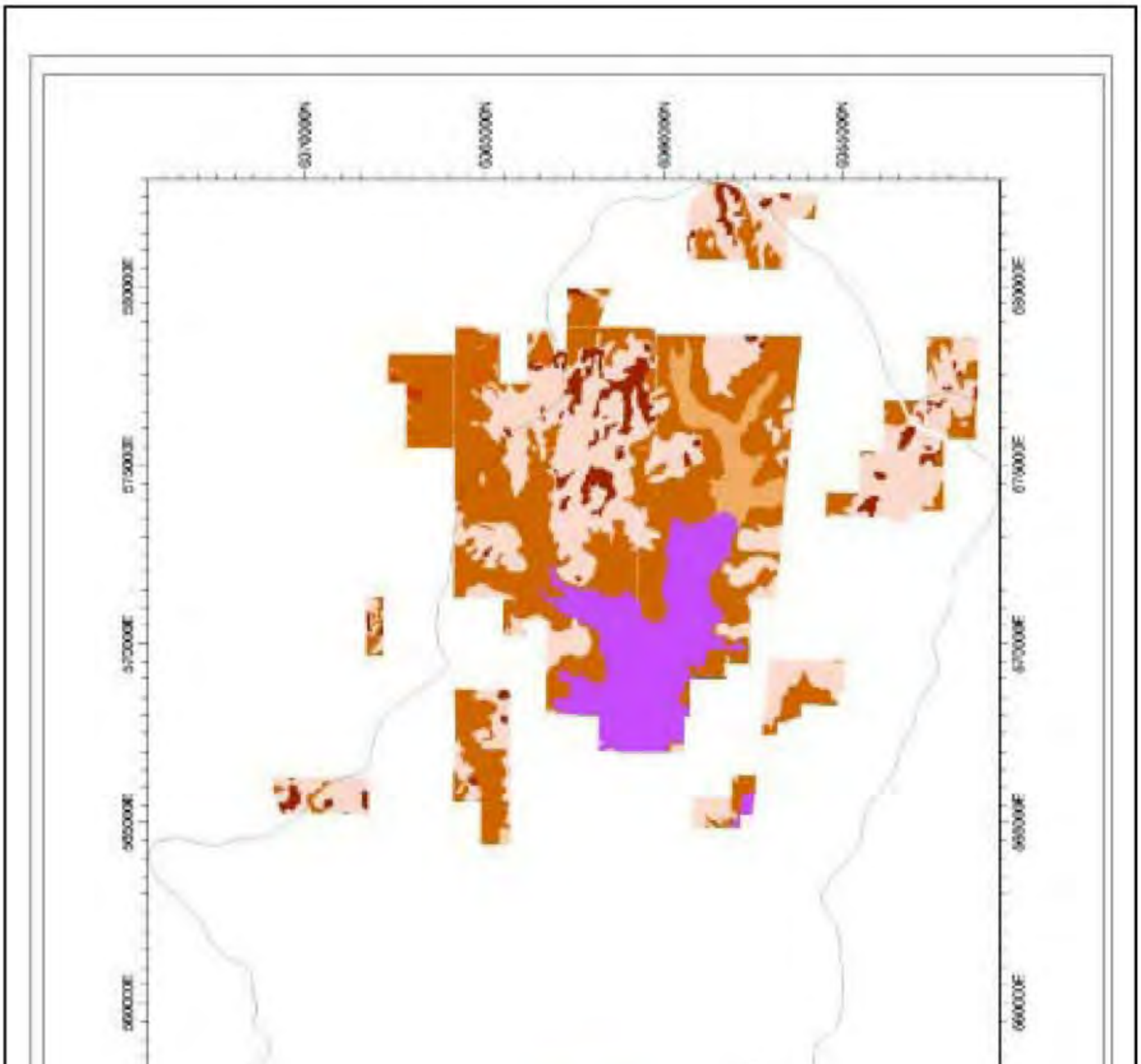


Figure 3.17: Spatial Intersection between current soil units and Landclass historical soils

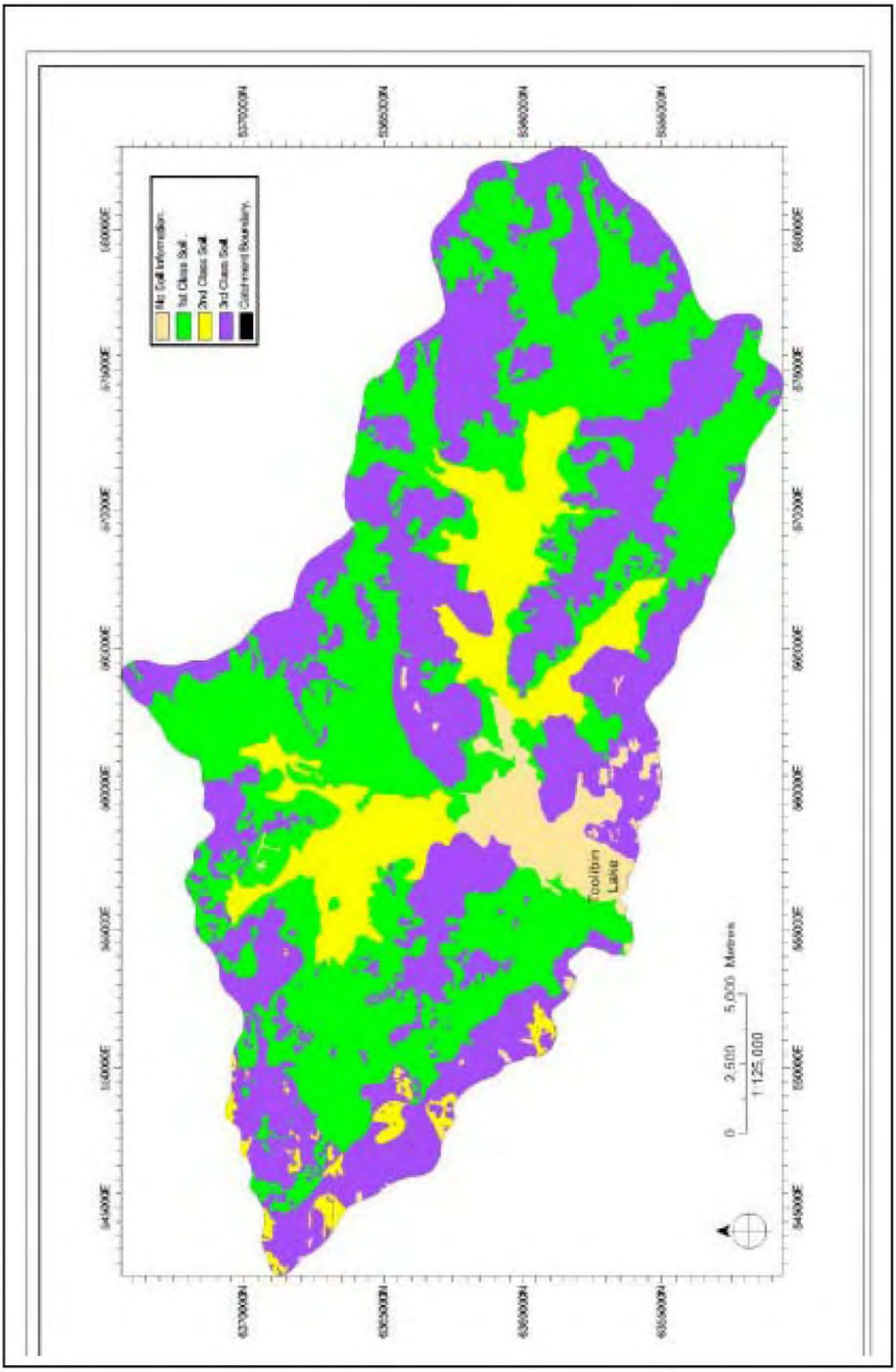


Figure 3.18: Reconstructed soil map (based on Landclass Soils)

3.10 Deriving slope information

A 10-metre resolution digital terrain model (DTM) was produced on MGE terrain analyst using the 2-metre contours supplied by the Department of Agriculture. The contour data had a maximum of 434 m and minimum of 294 m within the catchment.

The following steps were applied to derive the DTM:

1. Import the design features, reading the Z coordinate of the contour feature. (*File>Import>Design File Features* – depending on which way Z is elected to be brought in the next step may vary – see Terrain Analyst help Import design features)
2. Convert to a Tin (*Convert>Features to TIN*)
3. Use either *Export>Binary Coordinates* or Save as to store the data as an xyz file or as a ttn file on disk.
4. Select *Utilities >Show model Statistics* to verify that the model has been triangulated. (If the number of triangles is zero, the model has not been triangulated.)
5. Convert the Tin to a grid (*Convert >TIN to Grid*)- creates a grid model in memory and sets the active model type to grid. Specify the grid header, generalisation and position parameters, interpolation method (in the convert tin to grid dialog box). Planar interpolation is recommended for Tin models that have evenly distributed points. The method calculates a Z value for each grid post by using the X,Y coordinate of that grid post and interpolating a Z value on the TIN model. (Planar interpolation fits a plane through the three vertices of a triangle. The Z value of the X,Y coordinate is determinated by solving the equation for the plane (Terrain Analyst Online Help).
6. Define the grid position – Extent by shape, or Z value of shape, X origin, X minimum, Y origin, Y maximum, X end point, Y end point, minimum and maximum Z coordinates, Row spacing, Number of Rows, Number of Columns, rotation angle, skew angle.
7. *Save* grid

The DTM was exported to MFWorks to derive the slope classes as shown in Figure 3.19.

A per cent slope map was derived (using the MFWorks 'grade' operation, option average slope) from the DTM. The slope map was reclassed into five classes (Table 3.4) as established by the *Australian Soil and Land Survey Field Handbook* (1990).

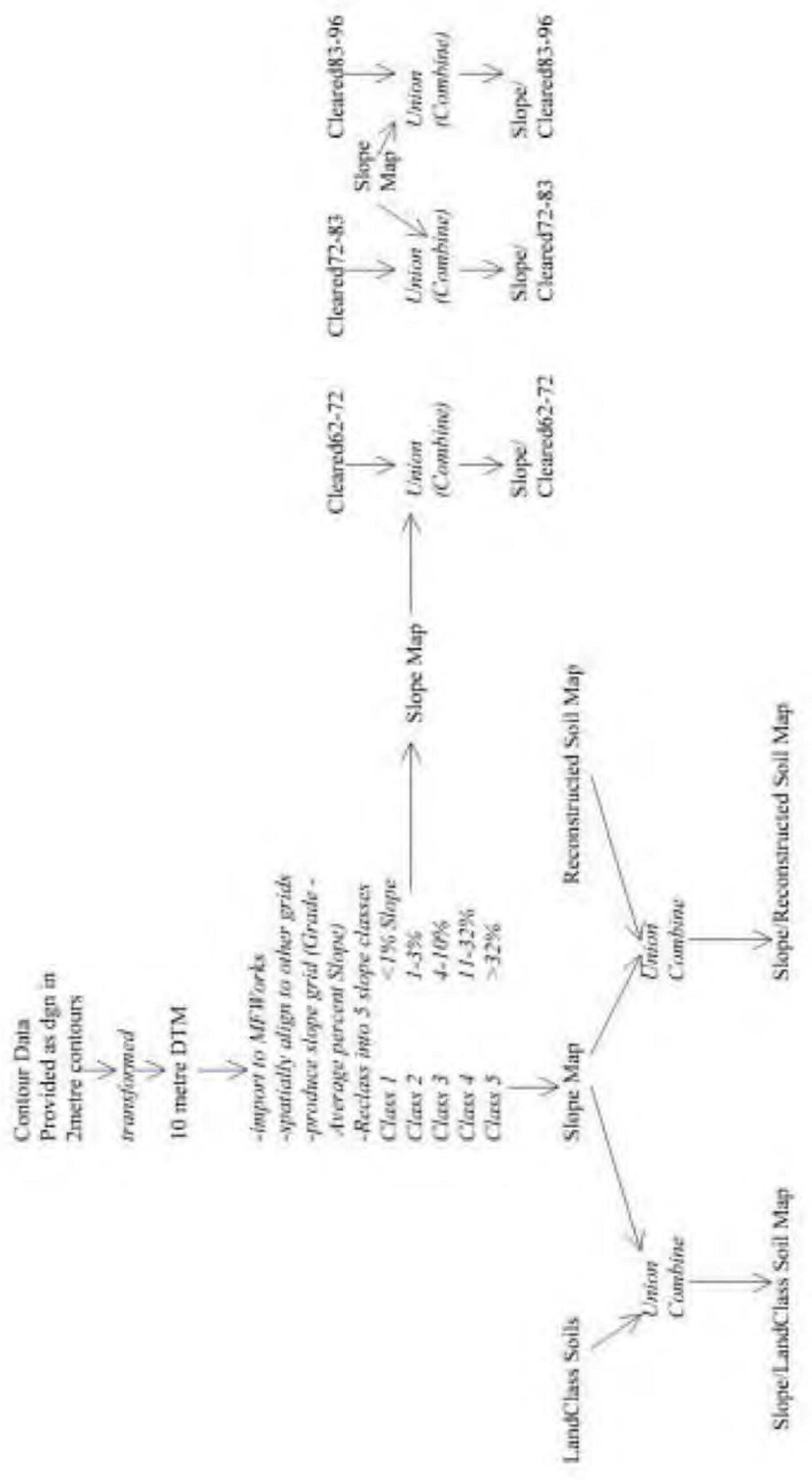


Figure 3.19: Flow diagram of the production of the slope data and the subsequent initial analysis

Table 3.4: Slope classes

Slope Class	*Slope Class Id*	*Slope Range (%)*
Level	1	<1
Very gently inclined	2	1-3
Gently inclined	3	3-10
Moderately inclined	4	10-32
Steep	5	>32

The slope map was combined with vegetation change maps to determine the dominant slopes cleared in each time period. The results are presented and discussed in Section 4.5.

3.11 Exporting the vector layers to MFWorks

To incorporate the slope it was necessary to use a raster-based GIS. MFWorks was chosen mainly due to the ease of data transfer. MGE grid analyst was the initial choice but problems associated with data transfer made it non-viable. MFWorks had the added advantage of being easy to use, an important advantage when time was an issue.

In order to take data from Geomedia into MFWorks the following process was adopted:

1. *Geomedia>SpatialTools> rebuild geometry* (set tolerance to 0.1) (if the program detected any problems with the geometry the export would not work) > *MFWorks menu> Export to MFWorks*, Assign a session name (directory where MFWorks output raster map will be placed), select connection where feature class is, the feature class and the attribute desired, set the cell resolution (10 metres) and the UTM Zone (50, South).

2. In MFWorks *open* a project and *import* the maps containing the exported attribute.

This was a simple and straightforward method. A 10-metre cell resolution was selected because:

1. Processing time of a smaller resolution grid would be increased.

2. The accuracy of the input vector maps, due to conflation in the original mosaics they were digitised from, had an average residual mean square error of between 12 (6 cells) and 19 (almost 10 cells) metres. With a cell resolution of 10 m in the raster map this translates to 1-2 cells.

3. Theoretical studies indicate cell sizes of 10 m x 10 m as adequate for mapping and spatial analysis at scale 1:20,000.

As only six layers could be imported at any one time it was necessary to align the grid origins in MFWorks so when operations were done the layers were correctly spatially located. The process to do this is as follows:

1. *Open* the layer that you wish to orient all other layers to. The initial layers brought in at the same time should all have the same grid extents so any one of these is suitable. *Map>Edit Geometry>* select the projection, which should be the one opted for when you exported the layer> record the origin coordinates. Take note of the azimuth value.
2. *Open* the layer to be orientated. Follow the same steps as in one and record the coordinates.
3. Subtract one from the other to determine the shift of the origin required. Divide each shift by the cell resolution to obtain the true shift. The accuracy will be slightly affected as a result of rounding.
4. Highlight (select) the map to be altered, *Window> Information>* Insert in map origin the respective northing and easting shifts> alter the azimuth value if necessary. Close information, *save* map.

To check for any shift, the same layer can be opened in Geomedia and using the coordinate readings in both, compare some common locations.

The following layers were imported into MFWorks:

- Vegetation Layer 1962 (vegetation classes 1-13 as described in Table 3.2)
- Vegetation Layer 1972(vegetation classes 1-13 as described in Table 3.2)
- Vegetation Layer 1983(vegetation classes 1-13 as described in Table 3.2)
- Vegetation Layer 1996(vegetation classes 1-13 as described in Table 3.2)
- Reconstructed Soil Map (Soil Class 1-3)
- Current Soil Map (Mapping Unit Classes 1-43)
- Catchment Boundary (for display purposes)
- Hydrology (for display purposes)
- *LandClass* excluding the duplicate polygons (soil class 1-3)
- *LandClass* excluding the duplicate polygons (historical vegetation classes 1-11 as described in Table 3.3)
- Terrain – DTM in 10 m resolution.

3.12 Production of change maps

The vegetation layers of 1962, 1972, 1983 and 1996 were included in the initial import into MFWorks. The process is presented in Figure 3.20. The first step in producing the change detection maps was to exclude class 13, which represented bare areas within a vegetation polygon from all the vegetation layers. A recode operation was done assigning a null value (e.g. void) to all class 13 cells and retaining the code of the remaining classes. The '*combine*' operation creates a map layer in which each cell is assigned a value which is derived from the unique combinations of all the cell values of the input layers (MFWorks tutorial manual). Combinations were done between the recoded maps 1962 and 1972, 1972 and 1983, and 1983 and 1996. These combinations resulted in maps with legends of up to 144 classes (i.e. all possible combinations between classes). These were then recoded into one of the four classes as presented in Table 3.5. Any other vegetation class in combination with class 10 was reclassed as revegetation. The reasoning was: in the 1983-96 change map, representing a 13 year period, it was reasonable to assume that the area could have been cleared and replanted with native vegetation; in the 1962-72 and 1972-83 change maps proximity to other cells designated revegetation made it plausible and probable that these were also revegetated areas.

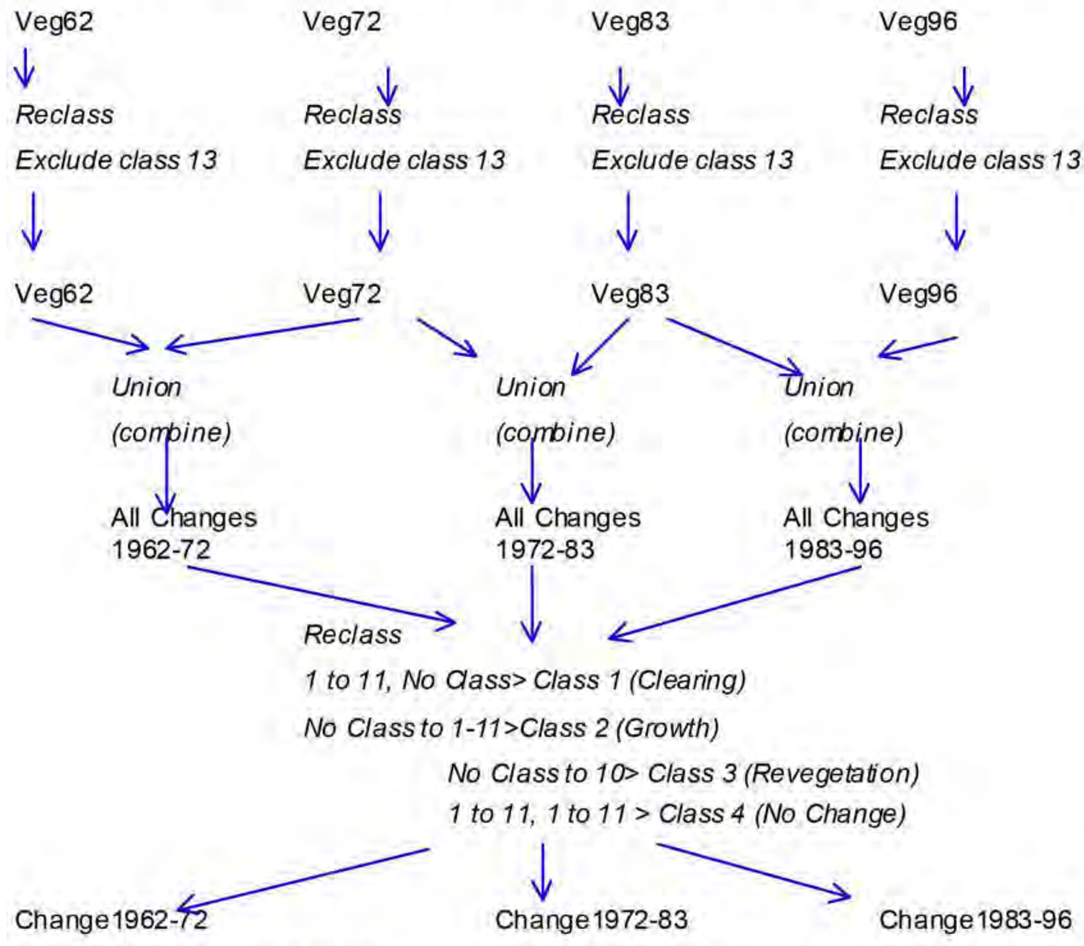
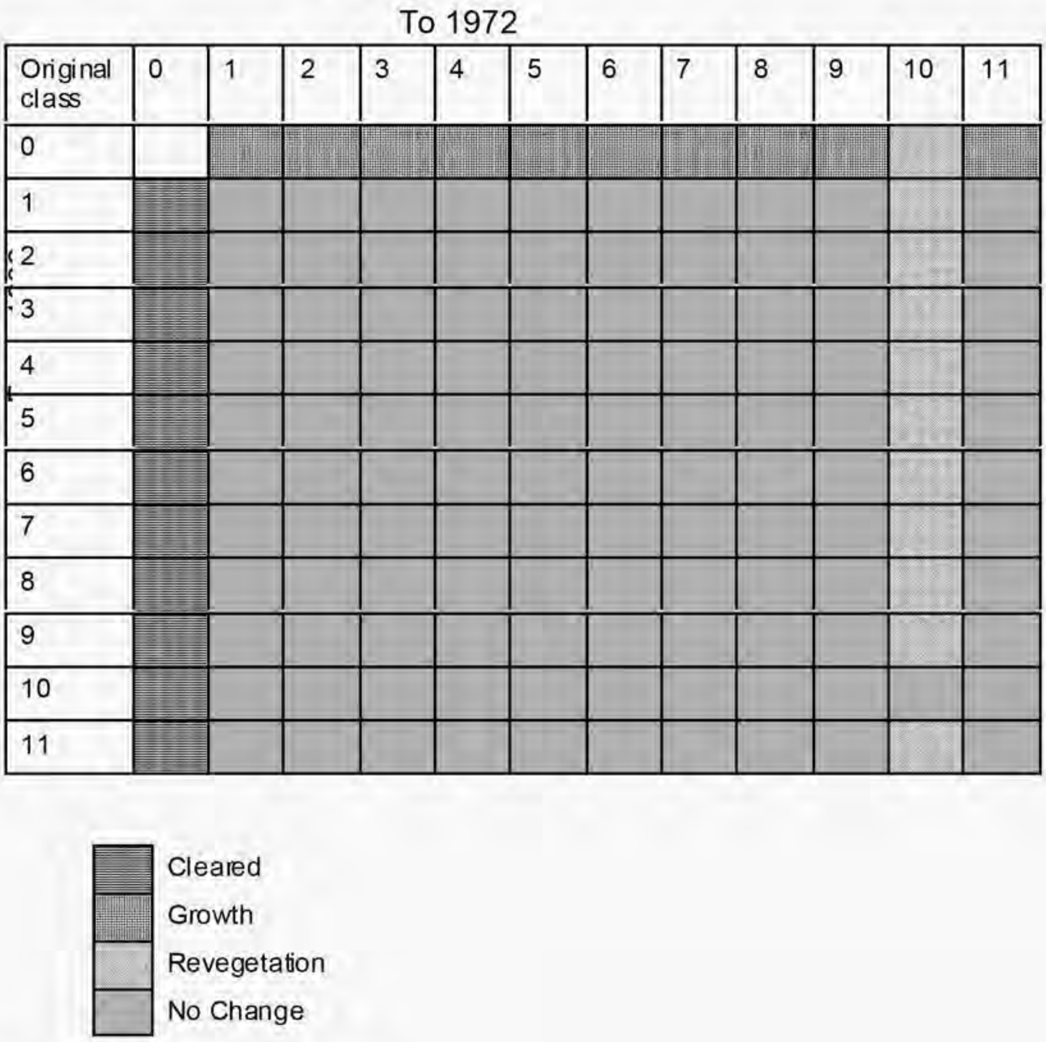


Figure 3.20: Flow diagram for the production of vegetation change maps

Table 3.5: Reclassification of change map classes

Change Map Class	Reclassed as	Description
(1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11) AND (null)	Class 1	Cleared
(null) AND (1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11)	Class 2	Growth
(null) AND (10); (1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11) AND 10	Class 3	Revegetation
(1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11) AND (1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 11); 10 AND 10	Class 4	No Change

Example of reclassing vegetation class combinations



Reclassification rules:

: input map classes

A= class(Map A)

B= class (Map B)

: output map classes

C= class (Map C)

: If A <1..9,11>, B <null> then C = 1

: If A <null>, B <1..9,11> then C = 2

: If A <1..9,11 or null>, B<10> then C=3

: If A <1..9,11>, B <1..9,11>, then C=4

: If A <10> , B <10>, then C=4

3.13 Spatial analysis of the relationship between soil type and vegetation clearance

In order to determine which vegetation classes were cleared and in what soil units, maps of cleared vegetation had to be derived (Figure 3.21). The union (all combinations) maps produced in Section 3.12 were recoded so that only the cleared vegetation in the original classes was left (Figures 3.22 to 3.24). The following rule was applied to this end, if one of 1,2,3,4,5,6,7,8, 9,10,11 AND null then assign class 1 to 11 respectively. The current soil map was then combined with the cleared vegetation maps to determine the dominant soil units cleared in each time period. The resulting legend showed the number of cells per class of vegetation in each soil class. These values were transferred to an Excel spreadsheet to compute the area for each vegetation class. Tables 4.7 to 4.9 show the intersections between the soil mapping units and the vegetation classes cleared between the respective years.

3.14 Slope and historical vegetation

The slope map was combined with the historical vegetation (*landclass* layer) to see if there was a relationship (Figure 3.25). The results are presented in Table 4.14 and discussed in Cection 4.6.

3.15 Slope and historical soil

The slope map was combined with the *landclass* soil map to determine if there was a relationship between slope and historical soil class. A frequency table (Table 4.16) and map (Figure 3.26) resulted from this procedure. The results are discussed in section 4.6.

3.16 Historical soil and historical vegetation layers

The historical soil map was combined with the historical vegetation to determine if certain vegetation classes correlated with certain soil types (Table 4.12 and Figure 3.27). The results are discussed in Section 4.6.

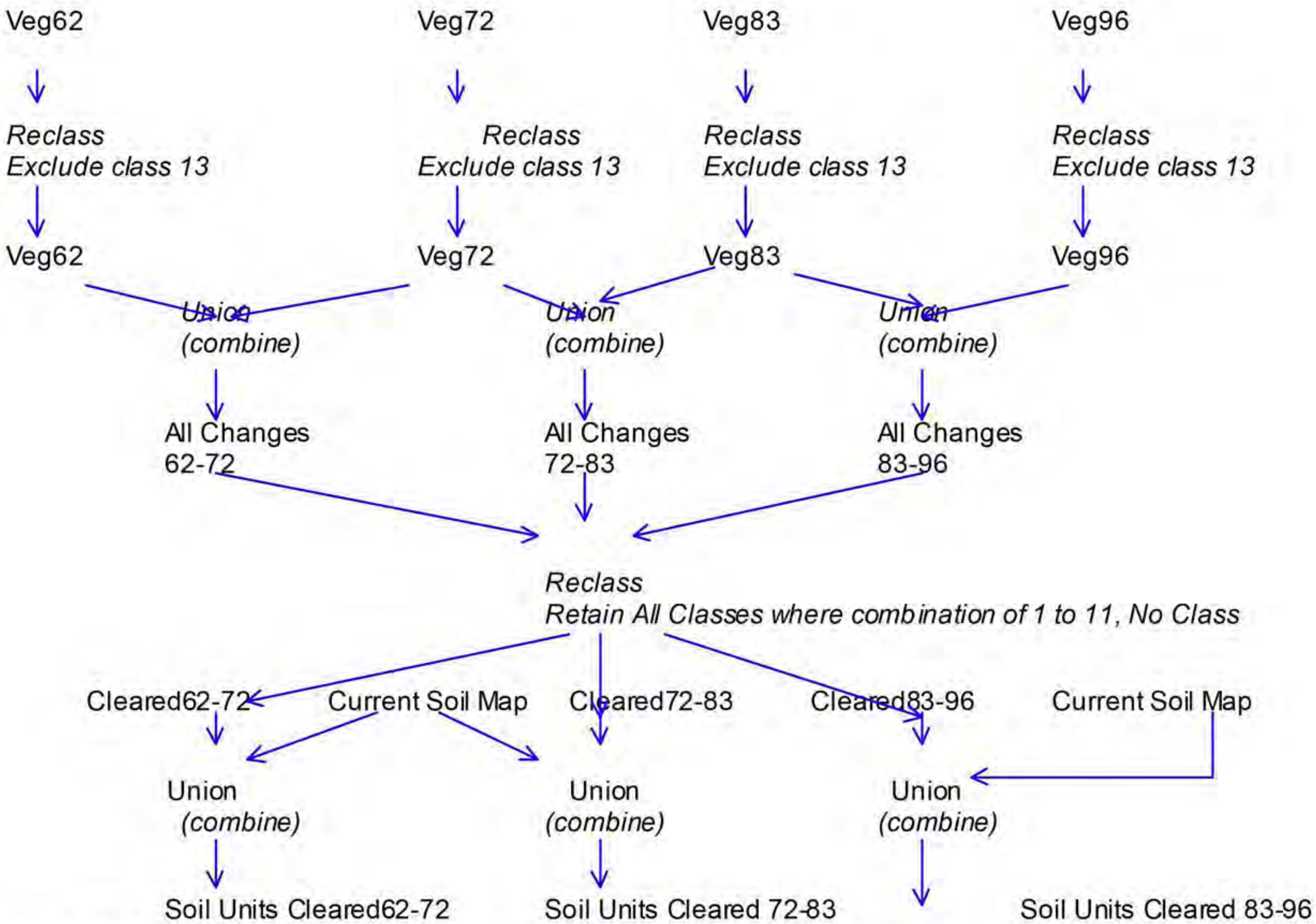


Figure 3.21: Flow diagram for production of main soil complexes cleared maps

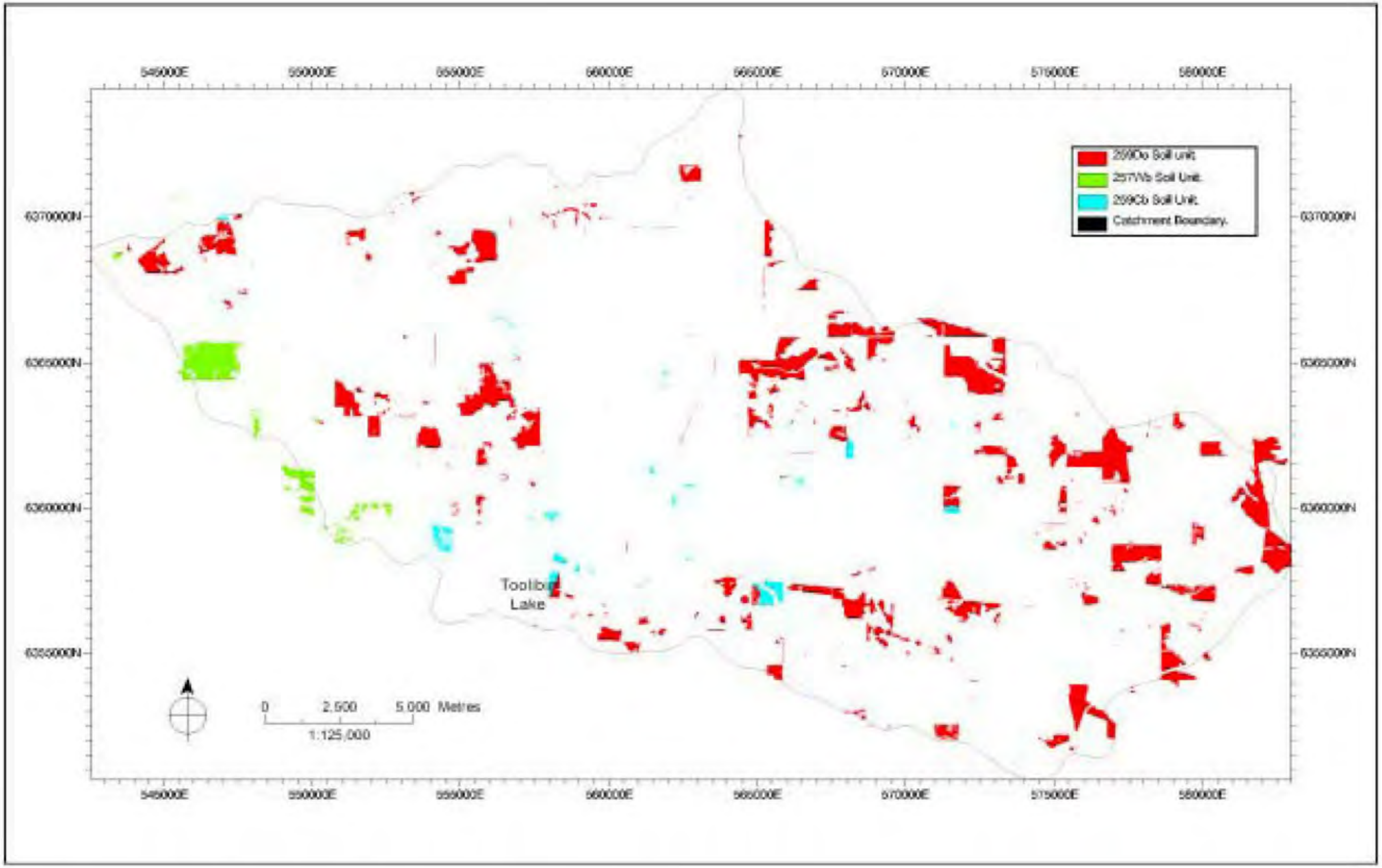


Figure 3.22: Main soil complexes cleared between 1962 and 1972

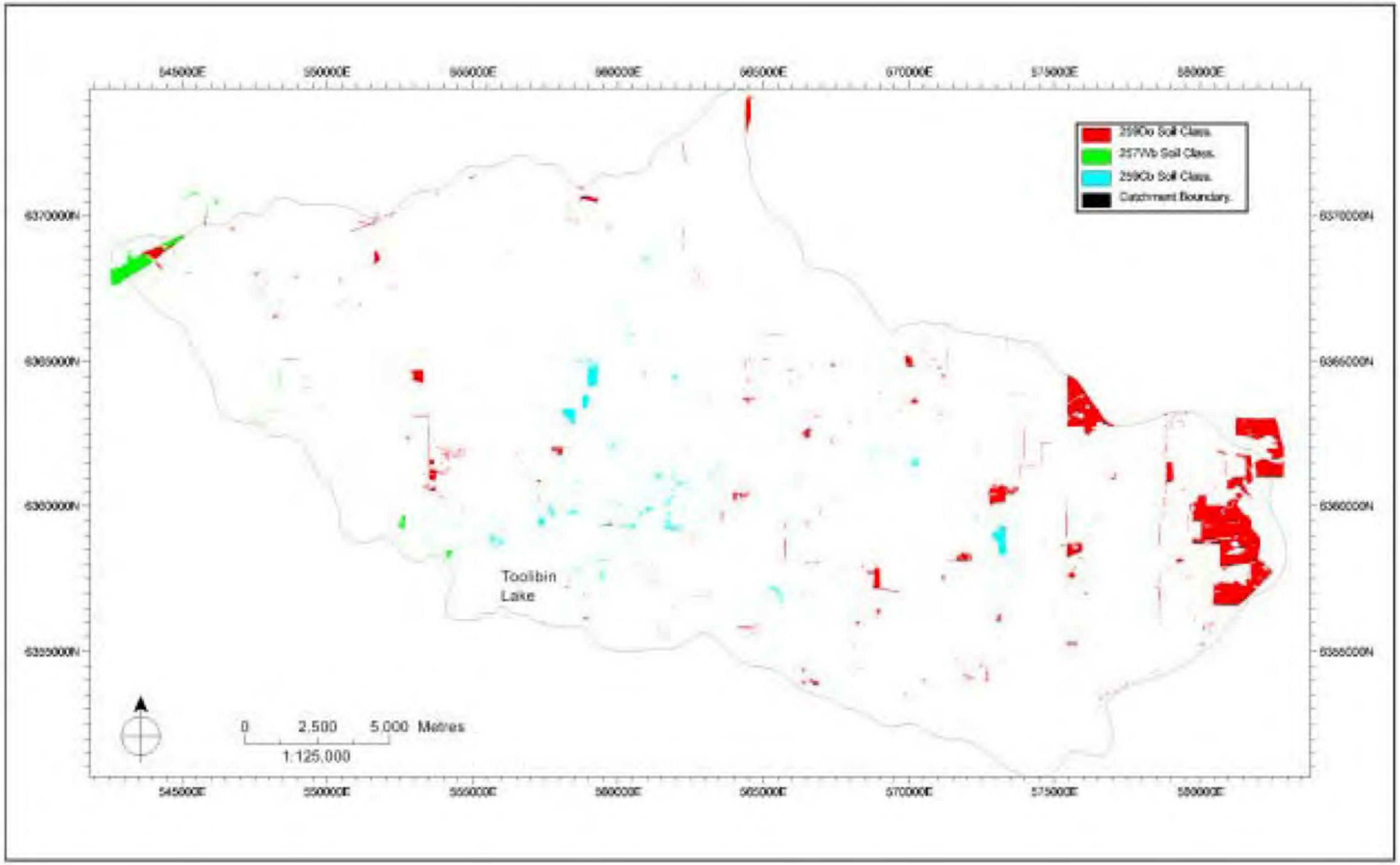


Figure 3.23: Main soil complexes cleared between 1972 and 1983

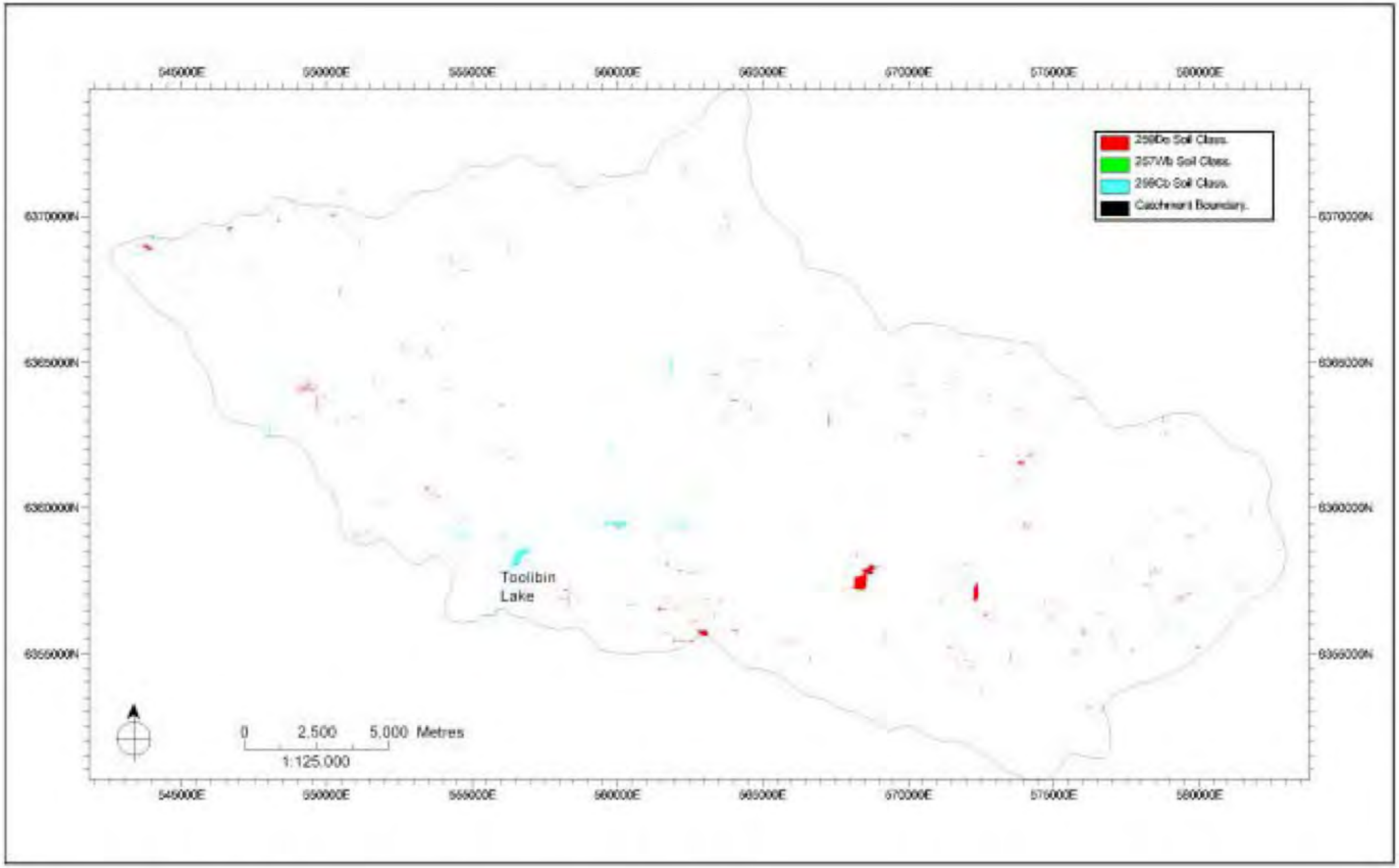


Figure 3.24: Main soil complexes cleared between 1983 and 1996

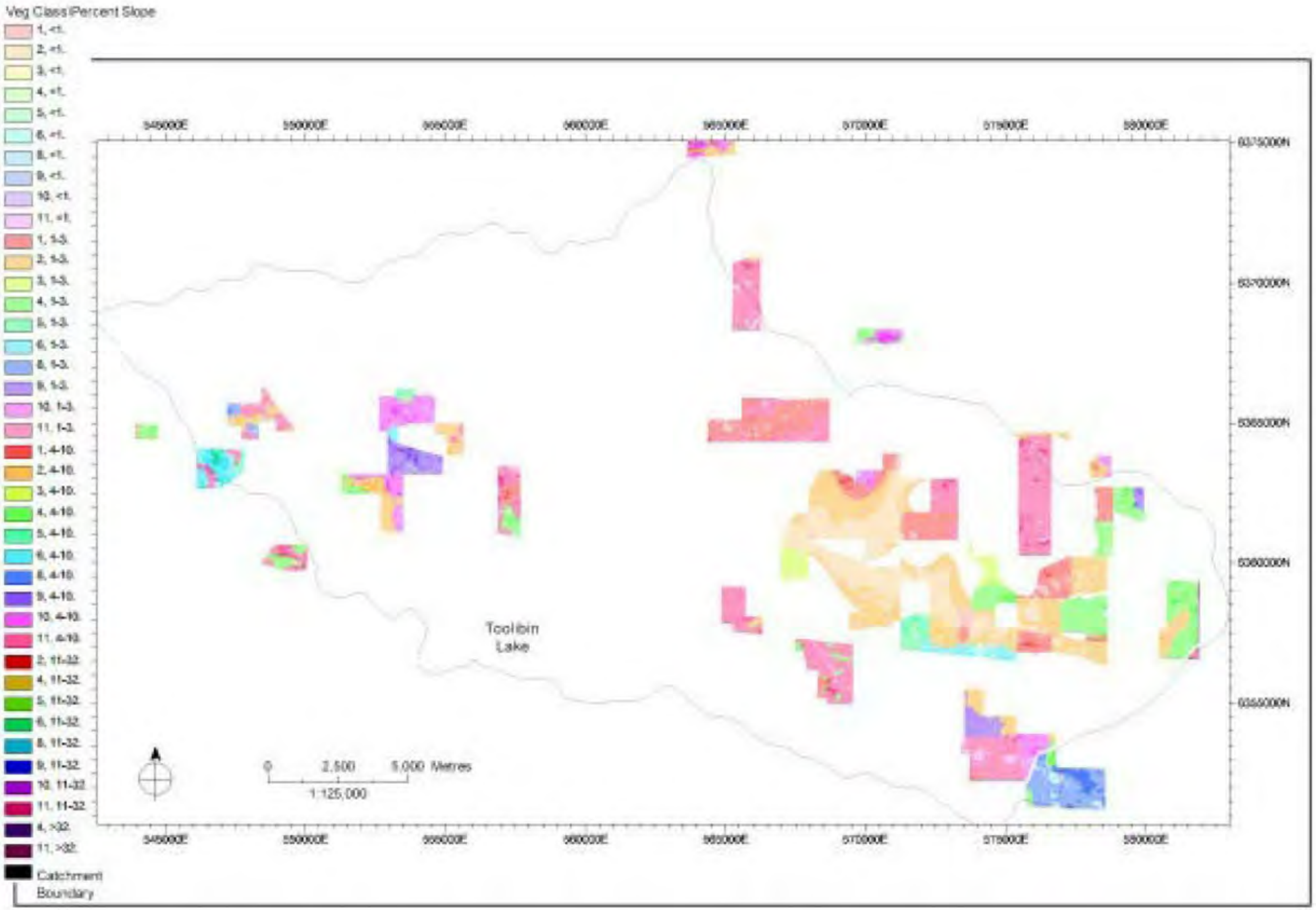


Figure 3.25: Spatial intersection of historical vegetation (11 classes) with per cent slope (five classes)

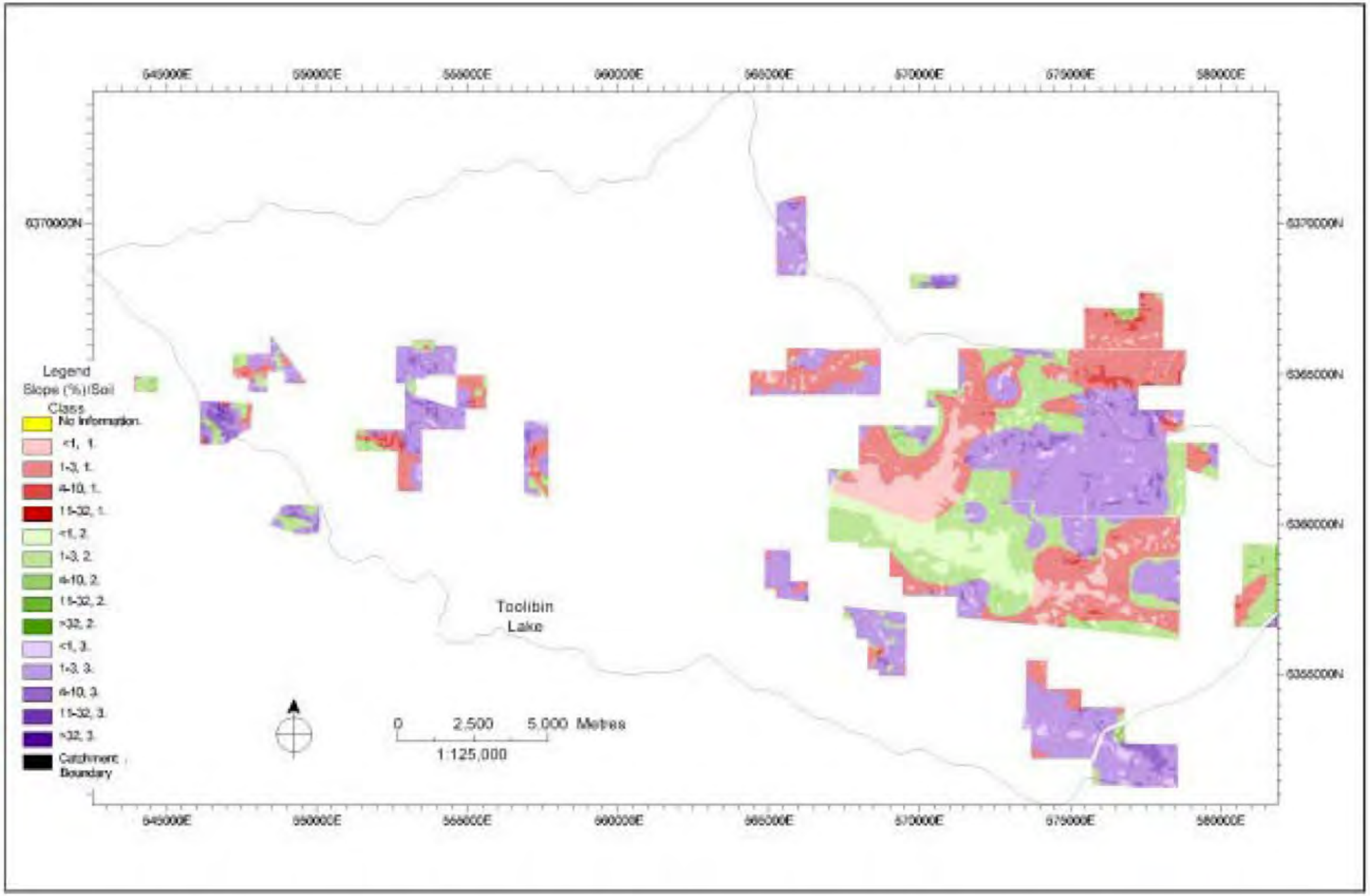


Figure 3.26: Spatial Intersection of per cent slope (five classes) with historical soils (first, second and third class)

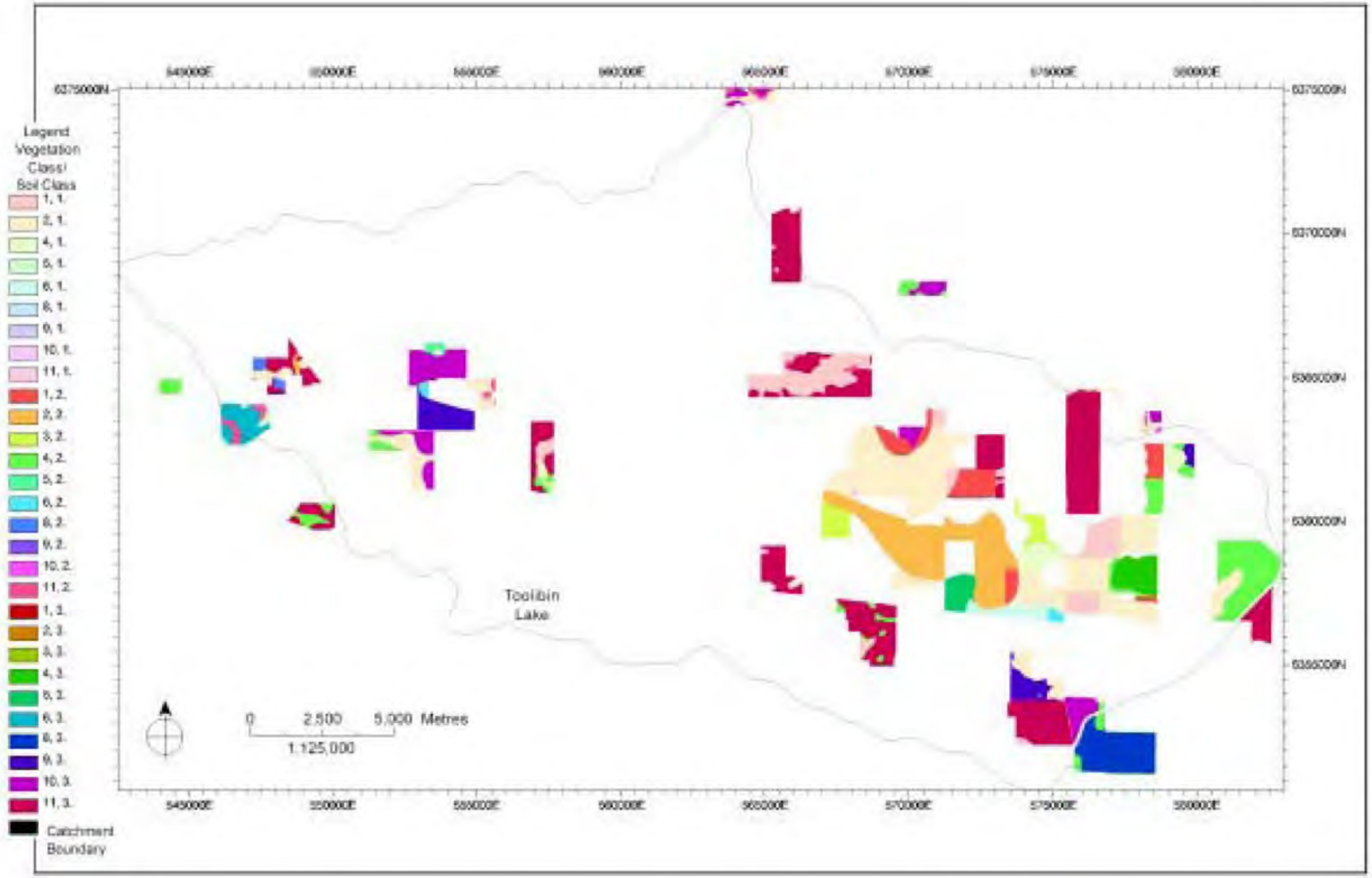


Figure 3.27: Spatial Intersection of historical vegetation (11 classes) with historical soil (first, second and third class)

3.17 Rule formulation

A set of rules was formulated based on the interactions of historical soil, slope and vegetation (see Section 4.7) which were implemented to produce maps of estimated historical vegetation for the catchment. Figure 3.28 is a flow diagram of the process up to and including derivation of the rules and the subsequent modelling. The rules were applied to the *landclass* soil with slope layer and the reconstructed soil with slope layer respectively.

The results of the combinations and resulting estimated maps were analysed and it was decided to reclass the historical vegetation into four classes: Class 1 and 2 remained the same, Class 3 represented the grouping of Classes 3 to 8 and Class 4 represented Classes 9 to 11. Classes 3 to 8 were combined, as in the original classification all were very small classes of low commercial value trees and woodland usually associated with second class soils. Classes 9, 10 and 11 were combined as they represented basically the same type of vegetation (scrub, box poison, blackboys) and are generally associated with third class soils.

Table 3.6: New vegetation classes after application of first set of 'rules'

Class	Old classes	Species composition
1	1	Morrel, salmon gum, mallee (dominance of trees associated with first class soils)
2	2	Salmon gum, jam (dominance of trees associated with first class soils)
3	3-8	Wandoo, mallee, mallet (dominance of trees associated with second class soils), morrel, stony poison, sheoak, sandplain, box poison (trees associated with second class soils)
4	9-11	Box and prickly poison, York Road poison, blackboys, scrub, mallee and scrub

This reclassed historical vegetation layer (Figure 3.29) was then combined with the historical soil map (Figure 3.8) to see if there was a definite correlation between vegetation class and soil. The results of this spatial analysis (Figure 3.30) are discussed in Section 4.8.

Similarly, the slope and soil tables were examined and because of the small number of records in the slopes above10 per cent three new slope classes were defined:

Table 3.7: New slope classes

Slope class	Identification	Slope range (per cent)
Level	1	<1
Very gently inclined	2	1-3
Gently inclined–steep	3	>3

These new slope classes were then combined with the soil (Figure 3.31) and new vegetation classes. A second set of rules (see Section 4.8 and Figure 3.32) was devised and applied to the *landclass* soil with slope layer and the reconstructed soil with slope layer respectively.

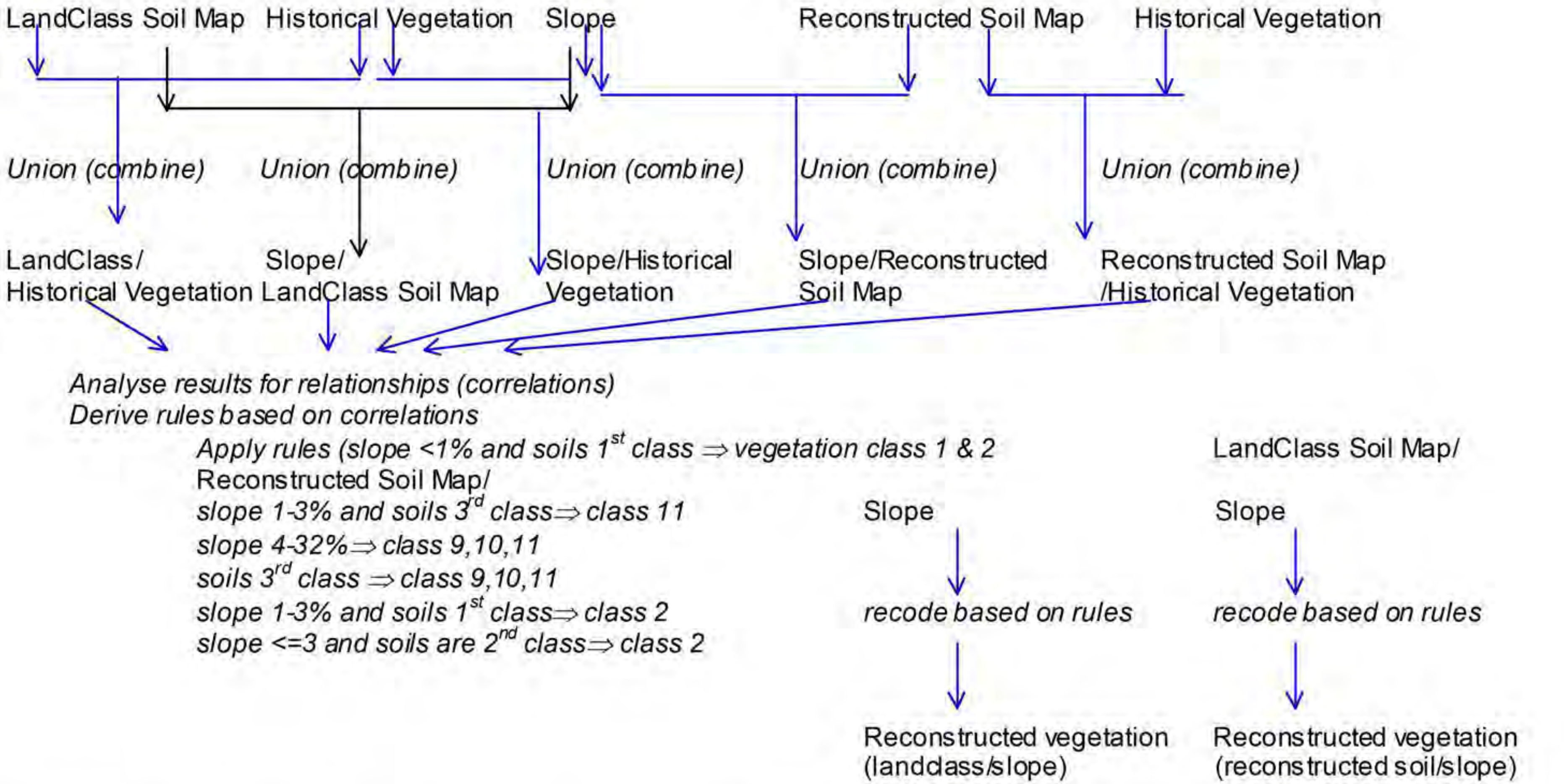


Figure 3.28: Flow diagram of the production of the layers whose correlations were used to derive the set of rules applied to produce a reconstructed historical vegetation map

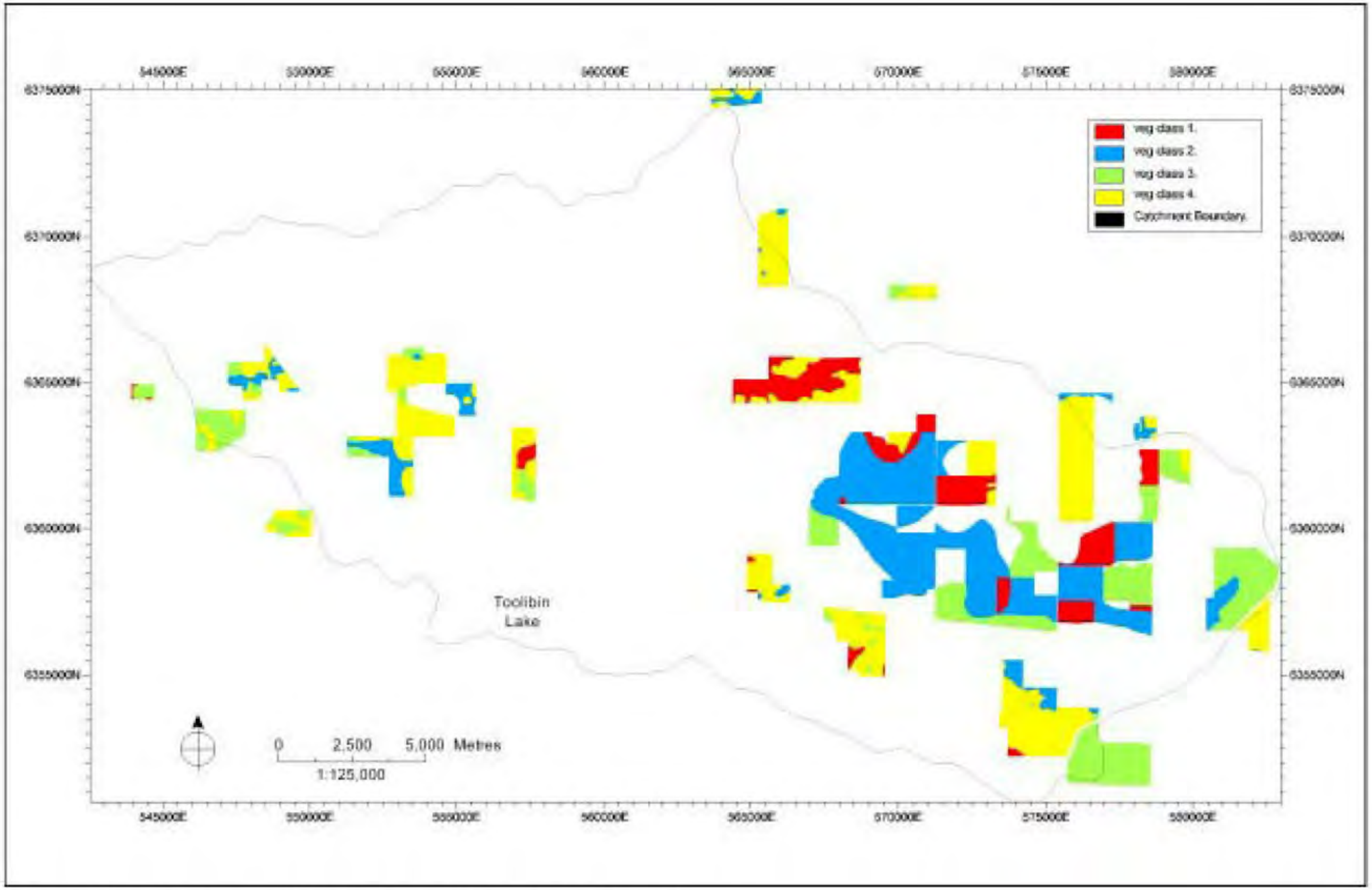


Figure 3.29: Reclassed historical vegetation (four classes)

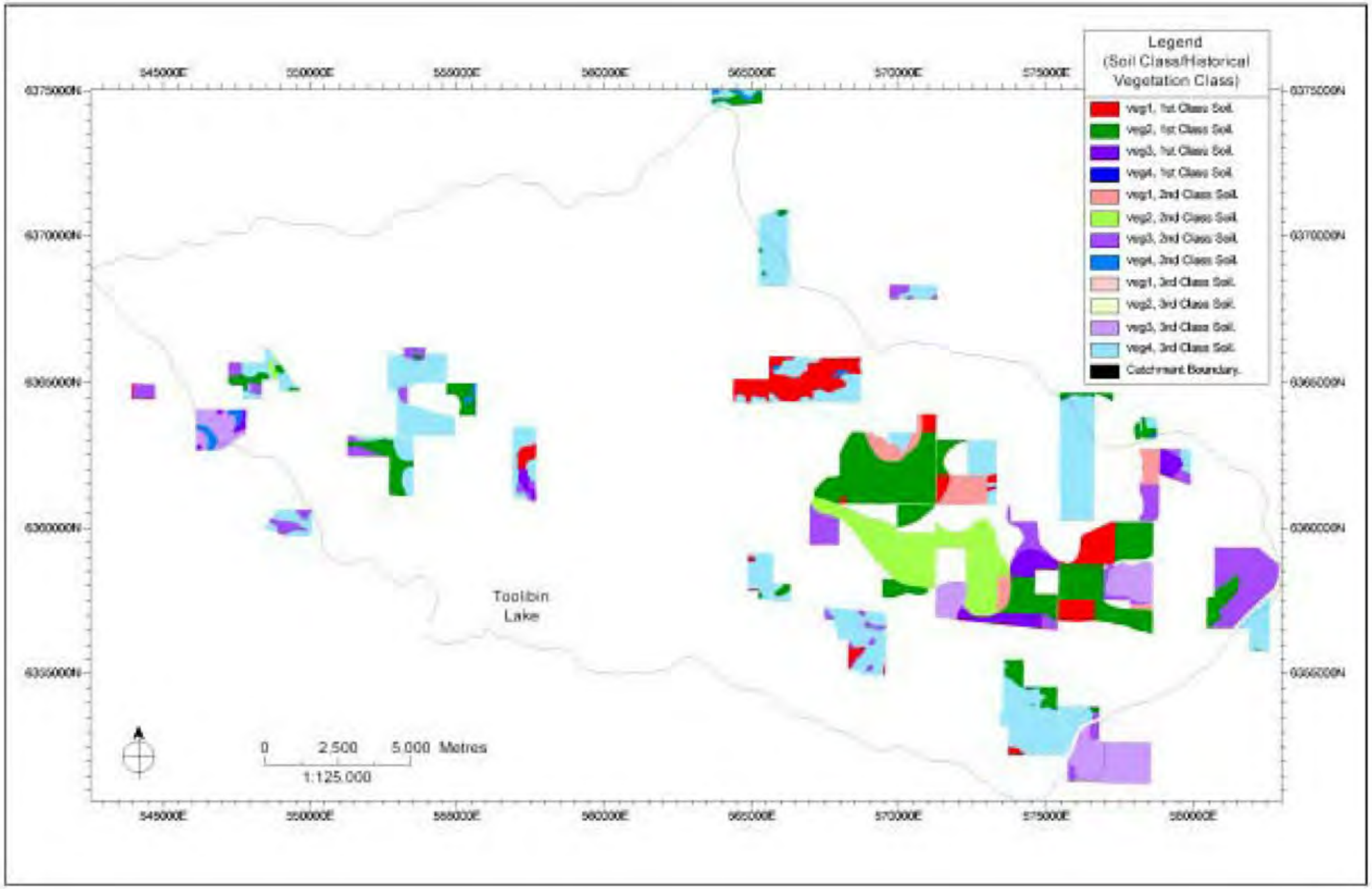


Figure 3.30: Historical vegetation (four classes) with historical soils (first, second and third class)

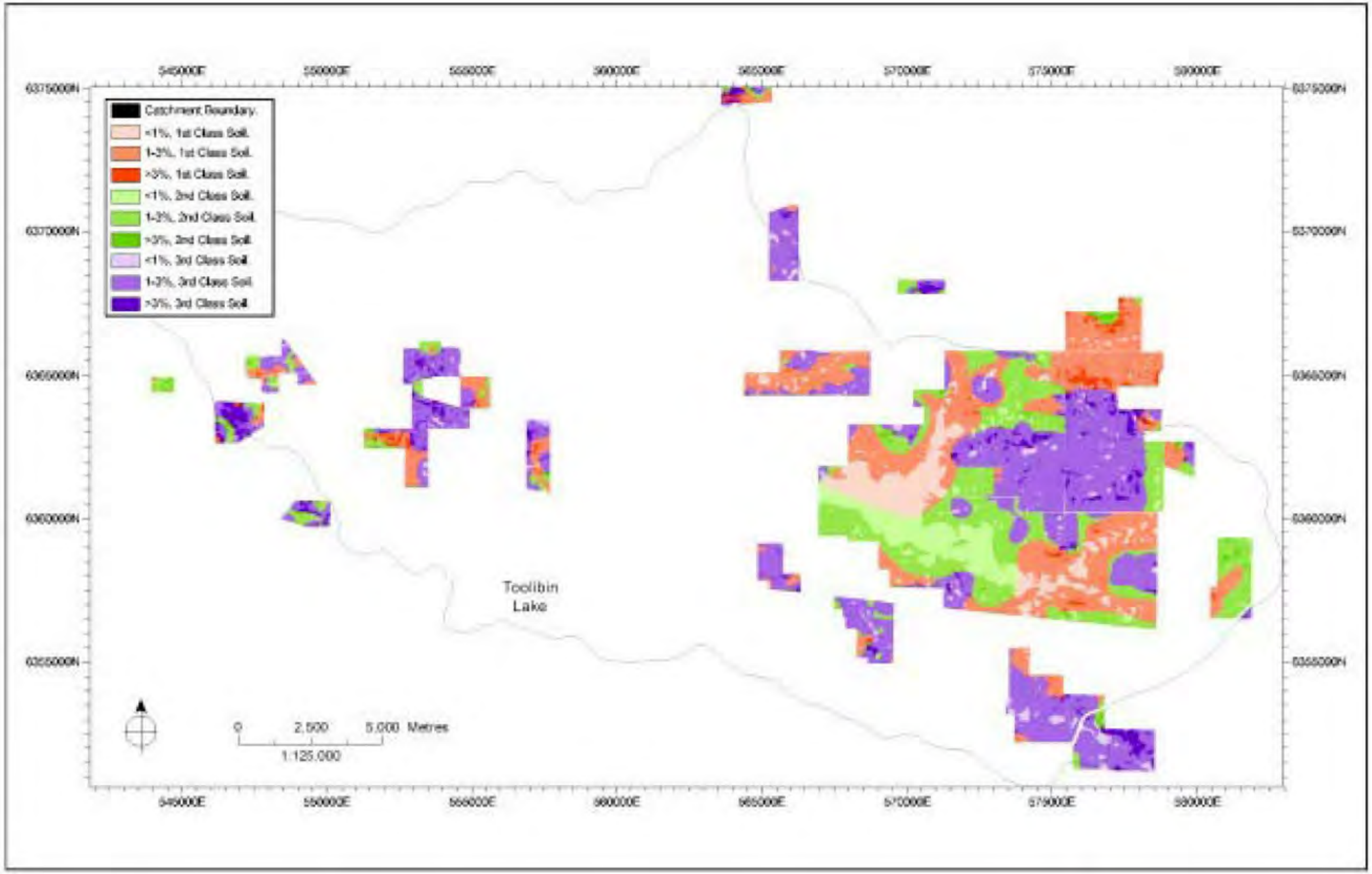


Figure 3.31: Per cent slope (three classes) with historical soils (first, second and third class)

4. Analysis

4.1 Characteristics of the vegetation layers (1962-1996)

Table 4.1 shows that most of the remnant vegetation patches were small, with 89 per cent under 10 ha in area. These patches only account for 18 per cent of the total remnant vegetation mapped in 1962.

Table 4.2 shows increased landscape fragmentation as the number of small patches of vegetation has risen since 1962, and larger patches (above 5 ha) declined. In 1962, remnants over 20 ha represented 72 per cent of the total area. In 1972 this was reduced to 57 per cent. The spatial analysis shows that 34 per cent of the remnant vegetation mapped in 1962 was cleared in the period 1962 to 1972.

Table 4.1: Digitised remnant vegetation patches for 1962

Area (ha)	Area of remnants (ha)	No of remnants	Per cent of total number	Per cent of total area
≤1	244.75	920	61.70	2.54
>1 and ≤2	193.20	135	9.05	2.00
>2 and ≤5	527.05	166	11.13	5.47
>5 and ≤10	749.23	106	7.11	7.77
>10 and ≤20	1170.78	82	5.50	12.15
>20 and ≤50	1516.30	47	3.15	15.73
>50 and ≤100	1376.32	19	1.27	14.28
>100 and ≤200	872.31	7	0.47	9.05
>200 and ≤500	2248.75	8	0.54	23.33
>500	982.42	1	0.07	10.19

Table 4.2: Digitised remnant vegetation patches for 1972

Area (ha)	Area of remnants (ha)	No of remnants	Per cent of total number	Per cent of total area
≤1	299.66	1164	67.48	4.66
>1 and ≤2	260.22	181	10.49	4.05
>2 and ≤5	536.02	168	9.74	8.33
>5 and ≤10	621.42	86	4.99	9.66
>10 and ≤20	1035.03	75	4.35	16.09
>20 and ≤50	887.07	29	1.68	13.79
>50 and ≤100	958.18	13	0.75	14.90
>100 and ≤200	906.13	6	0.35	14.09
>200 and ≤500	928.36	3	0.17	14.43
>500	0	0	0	0

In 1983 as in 1972, the trend of the smaller patches (up to 10 ha) is to increase, while the larger patches decrease (Table 4.3). The remnants greater than 20 ha represent only 47 per cent of the total. Total area covered by remnant vegetation has declined a further 20 per cent in area since 1972, losing 48 per cent since 1962.

For 1996 the number of patches smaller than 2 ha and those between 5 and 20 ha had increased (see Table 4.4). Clearing has reduced to 3 per cent. Forty-seven per cent of the remnants are greater than 20 ha. Remnant vegetation has increased since 1983 by approximately 70 ha. As most revegetated areas were clearly recognisable and excluded from these tables, it is assumed the increase is due to natural regeneration of areas that may have been fenced off from stock or left fallow.

Table 4.3: Digitised remnant vegetation patches for 1983

Area (ha)	Area of remnants (ha)	No of remnants	Per cent of total number	Per cent of total area
≤1	343.79	1380	71.02	6.59
>1 and ≤2	266.91	190	9.78	5.12
>2 and ≤5	582.83	180	9.26	11.17
>5 and ≤10	637.92	88	4.53	12.23
>10 and ≤20	888.39	64	3.29	17.03
>20 and ≤50	723.91	24	1.24	13.88
>50 and ≤100	864.51	12	0.62	16.57
>100 and ≤200	433.58	3	0.15	8.31
>200 and ≤500	474.23	2	0.10	9.09
>500	0.00	0	0.00	0.00

Table 4.4: Digitised remnant vegetation patches for 1996

Area (ha)	Area of remnants (ha)	No of remnants	Per cent of total number	Per cent of total area
≤1	388.90	1635	73.12	7.35
>1 and ≤2	300.45	211	9.44	5.68
>2 and ≤5	555.74	177	7.92	10.51
>5 and ≤10	780.75	107	4.79	14.77
>10 and ≤20	948.81	68	3.04	17.94
>20 and ≤50	660.33	22	0.98	12.49
>50 and ≤100	850.52	12	0.54	16.08
>100 and ≤200	305.98	2	0.09	5.79
>200 and ≤500	496.33	2	0.09	9.39
>500	0.00	0	0.00	0.00

Due to the difference in data structures the figures produced by Geomedia and MFWorks may differ slightly with regard to area cleared, regrown etc. MFWorks was limited to a 10 m cell size so is slightly less accurate but most analysis was done in MFWorks, with Geomedia mainly used for the preliminary stages. The percentages calculated in Section 4.1 are based on the Geomedia generated area for remnant vegetation.

4.2 Reconstructed soil map

The frequencies of the intersections in the respective soil classes are shown in Table 4.5. These frequencies were used to determine what soil class the rest of the region would have been in historic times.

Figure 3.18 shows the reconstructed soil map based on the reclassification of the soil units based on Table 4.5.

Table 4.5: Frequency and area of intersection between *Landclass* and current soil units

Soil Class	1	2	3	
	No of polygons/ area (ha)	No of polygons/ area (ha)	No of polygons/ area (ha)	Reclassed as soil class
257Ar_2	0	1 (8.9)	1 (10.1)	3
257Wb_1	6 (3.0)	9 (13.2)	7 (79.4)	3
257Wb_2	6 (32.8)	7 (94.1)	10 (142.1)	3
257Wb_3	6 (32.0)	4 (48.6)	6 (18.5)	2
257Wb_3d	2 (0.6)	1 (0.01)	2 (1.1)	3
257Wb_3g	0	2 (0.1)	5 (1.1)	3
257Wb_4sal	1 (0.1)	0	0	1
259Cb_1	18 (785)	24 (980)	7 (34.0)	2
259Cb_1fl	0	1 (1.4)	1 (1.4)	2
259Cb_2	1 (0.3)	0	0	1
259Do_1	75 (632.2)	85 (732.6)	92 (3697.8)	3
259Do_1s	9 (8.9)	11 (69.5)	68 (604.5)	3
259Do_2	79 (2860.7)	93 (1812.0)	71 (1201.8)	1
259Do_2sal	1 (5.3)	0	0	1
259Do_3	3 (12.5)	1 (6.1)	3 (35.1)	3
259Do_3d	11 (13.7)	1 (0.01)	6 (3)	1
259Do_3g	16 (10.8)	1 (12.6)	1 (0.1)	2
259Do_3r	6 (3.5)	0	0	1
259Do_4	10 (478.2)	2 (25.3)	0	1
259Do_5	1 (5.1)	1 (0.6)	2 (21.8)	3

4.3 Vegetation change maps

Table 4.6 presents the changes in vegetation for each time period analysed. The highest rate of clearing occurred in the period 1962-1972 (34 per cent) when large areas were cleared over the entire catchment (Figure 4.1). During 1972-1983 (Figure 4.2), the clearing of large areas decreased (20 per cent), being limited to three large areas on the margins of the western and eastern boundaries, and some smaller areas in the interior. Table 4.6 shows changes in vegetation over the 34 years 1962-1996. (Revegetation is not taken into account.) A small amount of growth was evident in each period, which could have been natural regrowth, or seasonal vegetation present at the time of data acquisition. Growth is not restricted to any particular area in any of the periods. Clearing reduced considerably in the 1983-1996 period (3 per cent). This may have been a result of the catchment management plan. Revegetation was most pronounced in the 1983-1996 period, as expected as a result of the catchment management plan. Revegetation is distributed mainly through the centre of the catchment, predominantly on the flatter slopes, along the lakes and through to the eastern boundary. Most revegetation has occurred on slopes between zero and 3 per cent inclusive (Table 4.11). The amount of native land cover reduced by half over the 34 years.

Table 4.6: Change in remnant vegetation for periods between 1962 and 1996

Area (ha)	1962-1972	1972-1983	1983-1996
Cleared area	3,754	1,470	207
Growth area	271	235	354
No change	7,133	5,936	5,937
Total area	7,404	6,171	6,291

The discrepancy between the cleared figures in Table 4.6 and the soil units cleared (Tables 4.7 to 4.9) is a result of no soil intersection with some areas.

4.4 Soil units cleared

As seen in Tables 4.7 to 4.9, in all three periods most clearing occurred in soil units 259Do_1 and 259Do_2. Unit 259Do_1 is composed of gravelly hill crests and summits, often bounded by breakaways with mainly shallow and deep sandy gravels with small areas of gravels and grey deep sandy duplex soils. Unit 259Do_2 is described as rises and occasional low hills with grey deep and shallow sandy duplex soils, often with alkaline subsoils. Unit 259Do_2 soils were reclassed as first class (based on the historical soil classification), while 259Do_1 was assigned third class soil. These patterns of clearing suggest that the first and second class soils with the flattest relief were cleared prior to 1962, so that the vegetated areas remaining were predominantly third class soils. These results are supported by historical records from the Northern Arthur River Wetlands Committee. Large scale clearing of better class clay soils was done after World War I with most heavy land under cultivation by the early 1930s and lighter sandier soils cleared in the late 1940s/early 1950s (Northern Arthur River Wetlands Committee 1987). Unit 259Do_2 could be a typical example of soil degradation, being first and second class soils in the surveys produced at the beginning of the century. Subsequent clearing of land for agricultural

Table 4.7: Cleared areas by vegetation class for 1962-1972

	Vegetation class (area in hectares)											Total
Soil class	1	2	3	4	5	6	7	8	9	10	11	hectares
257Ar_2	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_1	19.80	0.30	6.77	3.38	0.01	0	59.59	0	0	0	0	89.85
257Wb_1s	0.01	0.00	0.00	0.00	0	0	5.3	0	0	0	0	5.31
257Wb_2	126.84	3.50	22.31	20.33	0	0	39.02	0	0	0	0	212.00
257Wb_2g	0.00	0.03	0.00	0.00	0	0	0	0	0	0	0	0.03
257Wb_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_3	2.82	13.46	7.61	5.41	1.06	0	1.09	4.9	0	0	0	36.35
257Wb_3d	0.44	0.15	5.38	0.33	0	0	1.79	0	0	0	0	8.09
257Wb_3g	0.15	0.00	4.11	0.21	0	0	0	1.46	0	0	0	5.93
257Wb_3r	0.00	0.00	0.00	0.00	0	0	0	0.19	0	0	0	0.19
257Wb_3sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_1	15.33	3.30	2.03	0.00	5.08	0.23	17.37	52.19	0	0	0	95.53
259Cb_1fl	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_2	0.13	0.84	32.38	0.00	1.42	2.94	0.04	0	0	0	0	37.75
259Cb_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4fl	0.00	0.00	0.00	0.00	0.11	0	0	0	0	0	0	0.11
259Cb_4sl	0.00	0.00	0.00	0.00	0	0	2.74	0	0	0	0	2.74
259Cb_5	28.37	1.08	1.71	0.00	4.4	6.74	0.12	0	0	0	0	42.42
259Cb_5sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_1	435.53	147.54	122.67	56.55	74.42	5.06	450.23	247.04	3.48	0	0	1542.52
259Do_1s	27.96	9.42	7.23	7.38	13.54	0.09	85.44	62.41	0.01	0	0	213.48
259Do_2	523.38	119.07	200.15	27.13	19.29	3.83	288.9	85.37	0.17	0	0	1267.29
259Do_2d	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_2g	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_3	1.87	5.97	0.68	0.00	0.13	0	2.77	8.66	0	0	0	20.08
259Do_3d	0.02	0.16	0.00	0.00	0	0	0	0	0	0	0	0.18
259Do_3g	0.31	0.07	1.48	0.00	0	0	0	0	0	0	0	1.86
259Do_3r	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_4	1.65	0.84	0.05	0.00	0	0	0	0	0	0	0	2.54
259Do_5	15.36	10.34	27.59	0.00	70.88	0.8	0.33	12.75	2.23	0	0	140.28
259Do_5l	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_5s	1.14	0.01	0.57	0.00	5.67	0	0.4	0	0	0	0	7.79
259Ke_1	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3g	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
Total	1201.11	316.08	442.72	120.72	196.01	19.69	955.13	474.97	5.89	0	0	3732.32

Table 4.8: Cleared areas by vegetation class for 1972-1983

	Vegetation class (area in hectares)											Total
Soil class	1	2	3	4	5	6	7	8	9	10	11	hectares
257Ar_2	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_1	8.45	0.82	0.02	0.00	8.23	0.16	15.86	4.94	0	0	0	38.48
257Wb_1s	0.52	0.00	0.00	0.00	0	0	6.63	0	0	0	0	7.15
257Wb_2	4.65	3.23	0.00	0.00	5.91	4.29	5.69	18.29	0	0	0	42.06
257Wb_2g	0.00	0.00	0.00	0.00	0	0.12	0	0	0	0	0	0.12
257Wb_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_3	11.08	1.39	0.07	0.00	0.04	0.08	0	2	0	0	0	14.66
257Wb_3d	0.06	0.02	0.00	0.00	0	0	0	0	0	0	0	0.08
257Wb_3g	1.58	0.02	0.00	0.00	0	0	0	0.96	0	0	0	2.56
257Wb_3r	0.39	0.25	0.00	0.00	0	0	0	0	0	0	0	0.64
257Wb_3sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_1	53.54	34.21	2.99	0.00	0.41	5.06	0	5.22	0	0	0	101.43
259Cb_1fl	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_2	0.88	6.04	9.27	0.00	11.52	0.22	0	0	2.66	0.24	0	30.83
259Cb_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4fl	2.24	0.00	0.00	0.00	5.33	0	0	0	0	0	0	7.57
259Cb_4sl	0.00	0.00	0.00	0.00	2.28	0	0	0	0	0	0	2.28
259Cb_5	1.65	1.43	2.64	0.00	18.15	0.56	0.99	0	0	0	0	25.42
259Cb_5sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_1	87.92	39.82	49.43	28.16	15.32	7.35	336.33	145.86	1.04	0.22	0.22	711.67
259Do_1s	1.53	1.30	1.79	0.00	4.58	0.19	39.1	8.45	0	0	0	56.94
259Do_2	106.63	59.51	62.77	7.94	17.09	2.97	108.1	22.04	0.4	0.41	0	387.86
259Do_2d	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_2g	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_3	0.98	2.33	0.23	0.19	0	0	0	0	0	0	0	3.73
259Do_3d	0.82	2.54	0.00	0.00	0	0	0	0	0	0	0	3.36
259Do_3g	0.12	0.28	0.03	0.00	0	0.2	0	0	0	0	0	0.63
259Do_3r	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_4	0.06	0.23	9.60	0.00	0	0	0	0	0	0	0	9.89
259Do_5	2.32	1.28	1.20	0.00	0.44	1.93	0.39	0	2.52	0	0	10.08
259Do_5l	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_5s	0.00	0.09	0.00	0.00	0.01	0.65	0.29	0	0	0	0	1.04
259Ke_1	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3g	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
Total	285.42	154.79	140.04	36.29	89	24	513	208	7	1	0	1458.48

Table 4.9: Cleared areas by vegetation class for 1983-1996

	Vegetation class (area in hectares)											Total
Soil class	1	2	3	4	5	6	7	8	9	10	11	hectares
257Ar_2	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Ar_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_1	0.24	0.41	0.00	0.00	0	0.01	0	0	0.62	0	0	1.28
257Wb_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_2	0.50	1.81	0.01	0.00	0	0.19	0	0	0	0	0	2.51
257Wb_2g	0.00	0.00	0.00	0.00	0	0.06	0	0	0	0	0	0.06
257Wb_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_3	1.44	3.08	0.86	0.00	0.08	0	0	0.01	0	0	0	5.47
257Wb_3d	0.25	0.02	0.20	0.00	0	0	0	0	0	0	0	0.47
257Wb_3g	0.00	0.00	1.96	0.00	0	0	0	0	0	0	0	1.96
257Wb_3r	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_3sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
257Wb_4sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_1	0.29	5.94	1.19	0.00	1.46	0.33	0.14	0	0	0	0	9.35
259Cb_1fl	0.00	0.00	0.00	0.00	0	0	0.55	0	0	0	0	0.55
259Cb_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_2	2.77	1.80	3.61	0.00	2.88	0.02	2.51	0	0.01	0	0	13.60
259Cb_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Cb_4fl	15.62	0.01	0.00	0.00	11.06	0	0.03	0	0.19	0	0	26.91
259Cb_4sl	0.00	0.02	0.00	0.00	0.53	0	0	0	0	0	0	0.55
259Cb_5	0.91	1.20	1.76	0.00	1.15	0.09	0.37	0	0.49	0	0	5.96
259Cb_5sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_1	5.88	10.96	2.80	0.91	4.82	0.59	38.06	0.57	4.31	1.85	0	70.75
259Do_1s	0.27	0.51	0.14	0.00	0.02	0.05	0.18	1.02	0	0	0	2.19
259Do_2	6.82	18.12	4.71	0.06	0.6	2.6	1.67	0.26	0.36	0.26	0	35.46
259Do_2d	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_2g	0.00	0.12	0.00	0.00	0	0	0	0	0	0	0	0.12
259Do_2sal	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_3	0.11	0.70	0.40	0.03	0	0	0	0.01	0	0	0.02	1.27
259Do_3d	0.00	0.66	0.00	0.00	0.65	0.23	0	0	0	0	0	1.54
259Do_3g	0.00	4.65	0.22	0.00	0	0	0	0	0	0	0	4.87
259Do_3r	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_4	0.00	0.25	0.07	0.00	0	0.05	0	0	0	0	0	0.37
259Do_5	1.81	3.32	2.38	0.00	2.02	1.62	2.59	0	6.42	0	0	20.16
259Do_5l	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Do_5s	0.00	0.30	0.03	0.00	0.02	0.7	0.39	0	0	0	0	1.44
259Ke_1	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_1s	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
259Ke_3g	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0.00
Total	36.91	53.88	20.34	1.00	25.29	6.54	46.49	1.87	12.4	2.11	0.02	206.84

purposes exacerbated the salinity process, resulting in classification as soils with the characteristics of 259Do_2 (degraded by alkalinity/salinity).

From 1983 to 1996 the third most cleared soil was unit 259Cb_4fl, the freshwater lake phase of the Coblinine System. A large area on the north-western edge of Toolibin Lake was no longer vegetated in 1996. It is unlikely that this was cleared, rather that increased salinity resulted in plant morbidity on this shore. In 1988 Halse noted high salinity on the western shore and that all the trees had died.

4.5 Slope and vegetation change maps

Toolibin catchment has relatively low relief with slope mostly between 1 and 3 per cent (Table 4.10 and Figure 4.5).

Table 4.10: Total area covered by the defined slope classes

Slope class (per cent)	Area (ha)	Per cent of catchment
<1	9,545	19.8
1-3	35,280	73
4-10	3,020	6.3
11-32	49	0.1
>32	13	0.03

Table 4.11: Slopes cleared and revegetated over the 34 year period

	Area cleared (ha)			Revegetated
Slope (per cent)	1962-1972	1972-1983	1983-1996	1983-1996
<1	291	172	62	568
1-3	2860	979	127	754
4-10	362	138	18	47
11-32	5.6	2.08	0.3	0.03
>32	6.6	6.4	0.02	0.9

In the period 1962-1972 (Figure 4.6) slopes between 1 and 3 per cent were most extensively cleared. From the correlation derived in Tables 4.14, all three historical soil classes were highly represented in slopes of 1 to 3 per cent, with third class soils dominant. Current soil mapping units 259Do_1 and 259Do_2, the most extensively cleared in 1962-1972, were reclassified as third class and first class soils respectively. 259Do_1, reassigned third class corresponds with historical vegetation class 11 (see Table 3.3). This vegetation class was the most dominant in the slope between 1 and 3 per cent (Table 4.16). Historically, these slopes were vegetated with scrub, blackboys, box poison and mallee. Class 2 is the second most dominant vegetation type in slopes between 1 and 3 per cent (Table 4.16). This class represents trees associated with first class soils.

Similarly, 1972-1983 (Figure 4.7) was also characterised by clearing, mainly in the slopes of 1 to 3 per cent and on soil units 259Do_1 and 259Do_2.

Between 1983 and 1996 (Figure 4.8) most clearing occurred on slopes between 1 and 3 per cent. Clearing levels reduced considerably compared to previous years. Revegetation programs had commenced and slopes up to 4 per cent were most extensively revegetated.

These patterns suggest that the flattest slopes (<1 per cent) were cleared prior to 1962 particularly as these (according to the correlations in Table 4.16) were first class soils. From 1962 to 1972 the next less steep slopes were cleared, ranging from first to third class soils according to the spatial analysis (Table 4.16). As the lower slopes had been cleared and farmed longest, the soil was most degraded (through salinity, waterlogging, loss of fertility). Hence these slopes of up to 3 per cent were revegetated first. Soil degradation in these areas would have made the soil unproductive so revegetating waterlogging and drainage lines would produce the most significant improvements to the soil and the water quality flowing into the catchment.

Figure 4.4: Per cent slope (five classes)

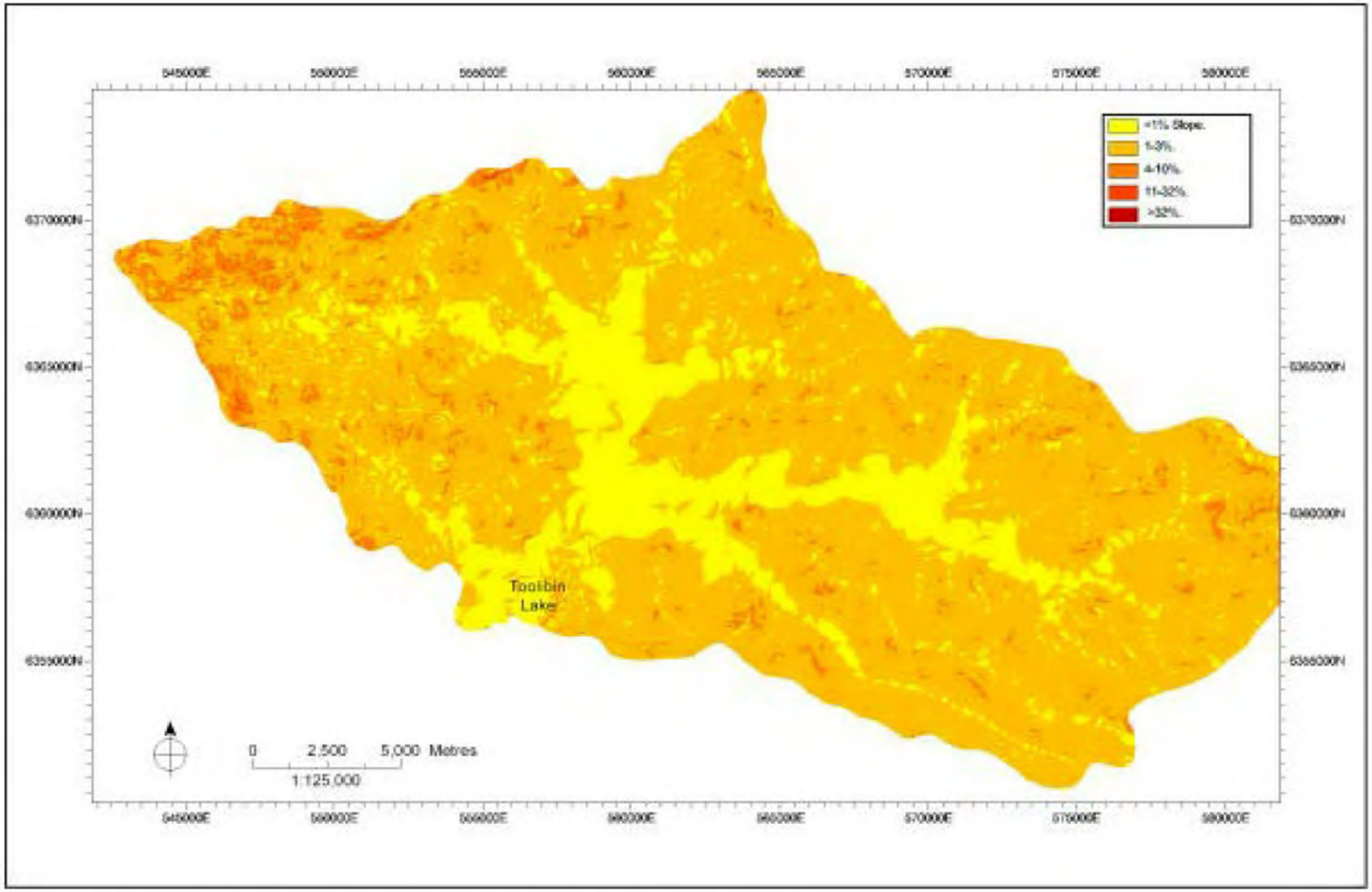


Figure 4.5: Slope of vegetation cleared between 1962 and 1972

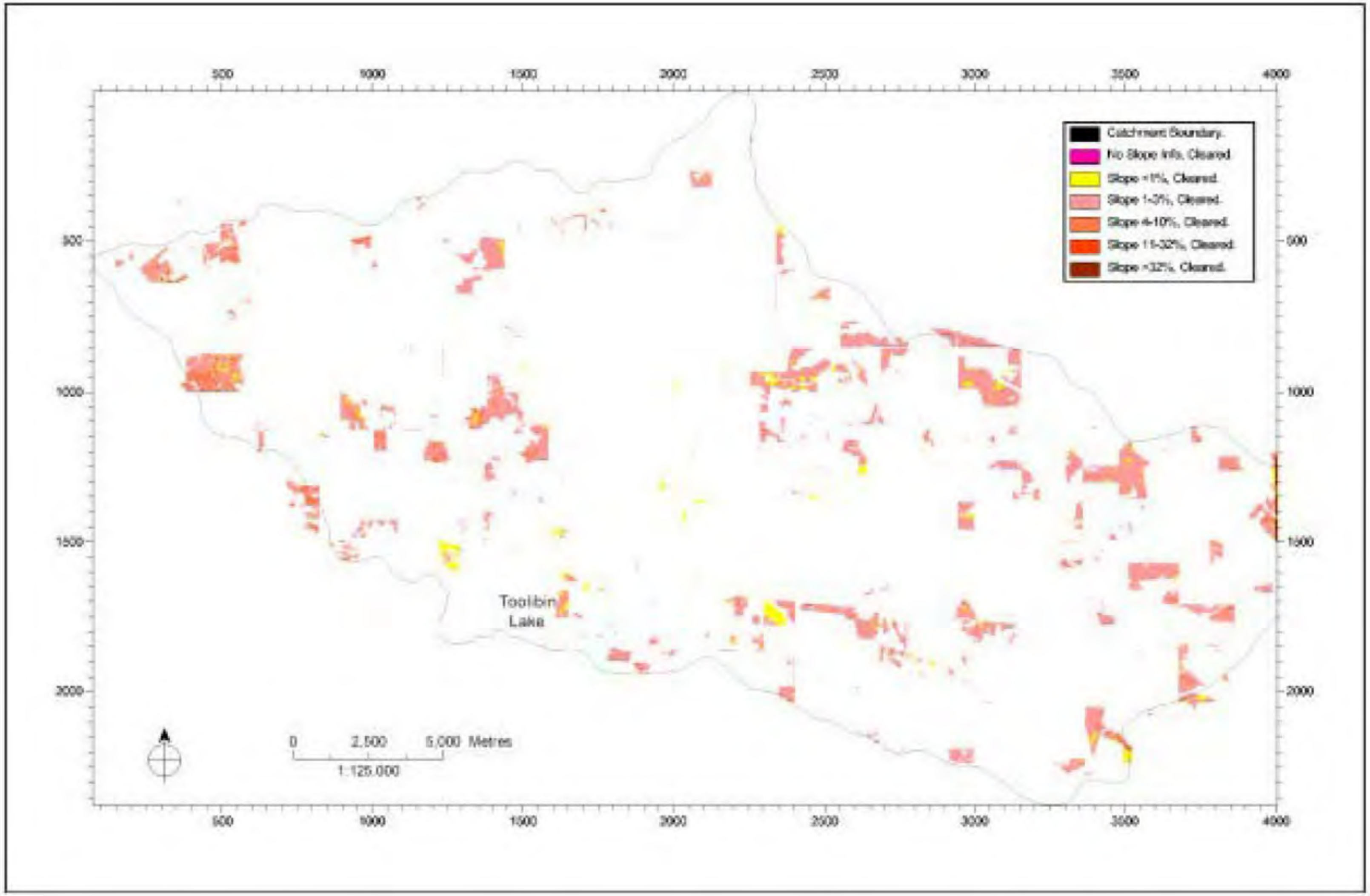


Figure 4.6: Slopes of vegetation cleared between 1972 and 1983

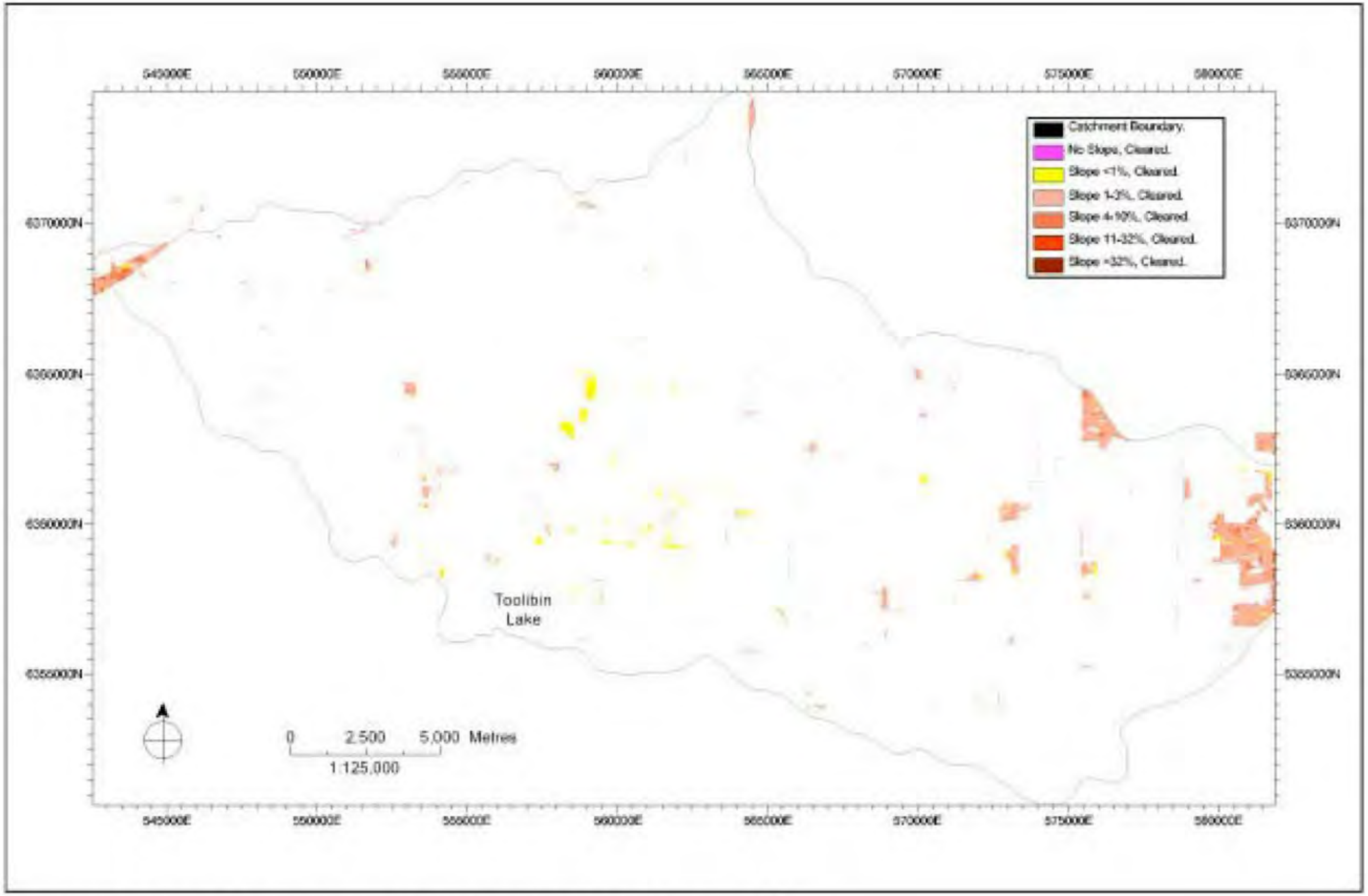


Figure 4.7: Slopes cleared and revegetated between 1983 and 1996

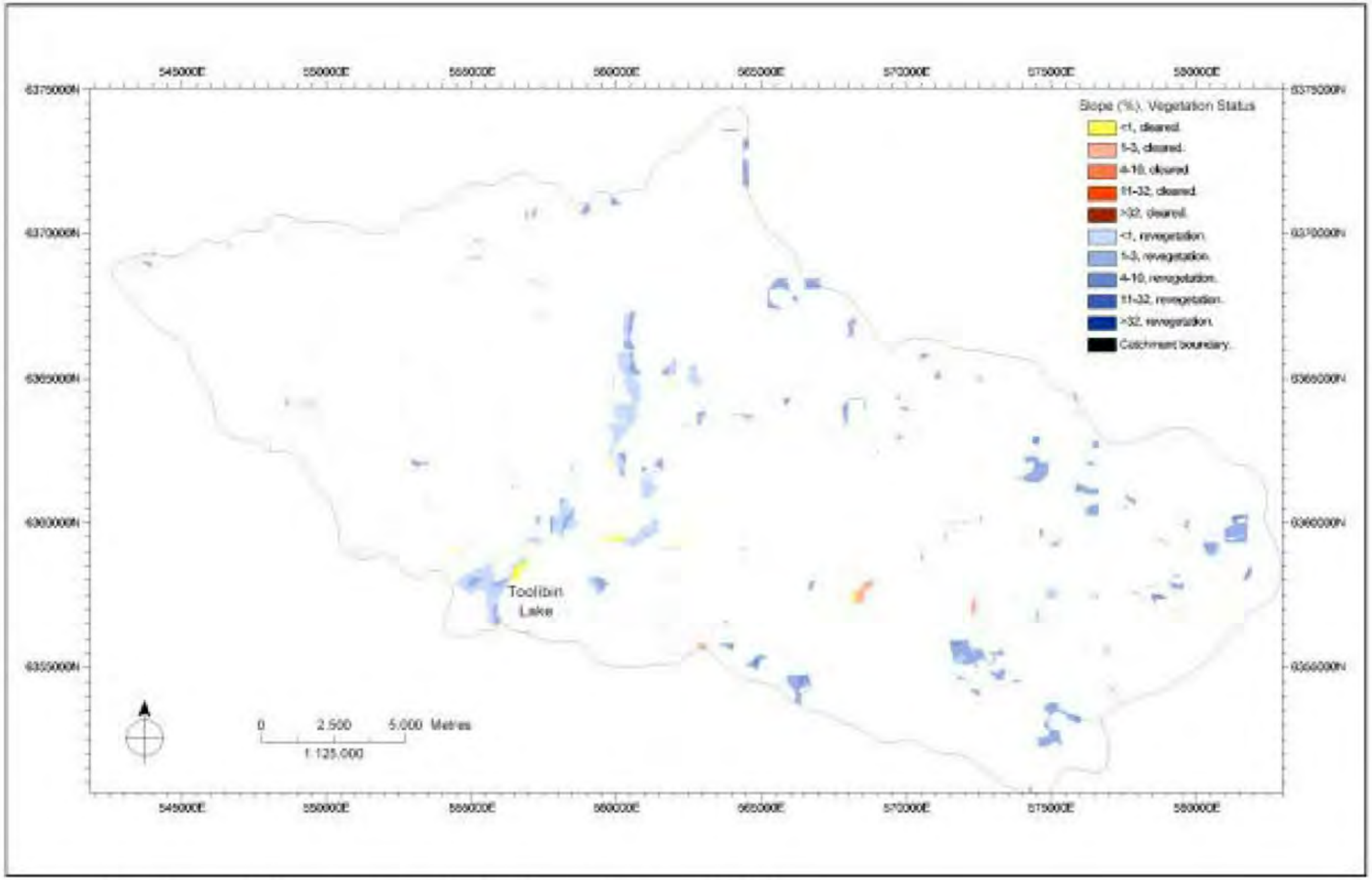


Figure 4.8: Per cent slope revegetated between 1983 and 1996

4.6 Slope and historical layers

Tables 4.12 to 4.13 were derived from the spatial intersection of historical soil and vegetation data (Figure 3.27). Code descriptions are in Table 3.3.

Table 4.12: Historical soils with historical vegetation (bold dominant, italic second)

Soil class	Vegetation class (ha)										
	1	2	3	4	5	6	7	8	9	10	11
1	*765.2*	**2101.28**	0	200.32	23.22	103.64	0	0.2	2.09	2.33	12.31
2	391.62	**965.54**	188.42	*772.78*	29.39	34.78	0	35.2	0.44	5.40	84.41
3	8.96	8.4	0.9	189.34	116.76	147.44	0	397.08	321.1	*530.21*	**2,194.62**

Note: There is no class 7 as it was represented by one record in the original historical vegetation layer which was subsequently excluded as it was a duplicate.

Table 4.13: Composition of dominant vegetation by soil class

Soil class	Dominant vegetation	Vegetation class
1	Salmon gum, jam, morrel, mallee	**2** (2101.28 ha), 1 (765.2)
2	Salmon gum, jam, wandoo, mallee, mallet, morrel	**2** (965.54), 4 (772.78)
3	Scrub, box poison, blackboys	**11** (2194.62), 10 (530.21)

Vegetation classes 1 and 2 are dominated by trees associated with first class soils (morrel, salmon gum, York gum, jam); classes 3 to 8 by trees that correspond to second class soils (wandoo, sheoaks, mallee, mallet); and classes 9 to 11 by vegetation associated with third class soils (poisonous native shrubs, scrubland (blackboys, scrub) and mixed woodlands such as stunted mallee, wandoo).

Tables 4.14 and 4.15 were derived from the spatial intersection of historical vegetation and slope data (Figure 3.25).

Table 4.14: Slopes with historical vegetation (bold dominant, italic second)

Slope class (%)	Vegetation class (ha)										
	1	2	3	4	5	6	7	8	9	10	11
<1	150.22	**1223.47**	7.46	36.02	12.76	25.2	0	52.71	13.53	31.55	134.62
1-3	982.23	*1777.94*	183.35	896.07	138.66	181.17	0	306.55	271.63	419.91	**1917.82**
4-10	38.4	79.34	0.6	77.37	18.82	74.24	0	76.71	40.1	*93.28*	**140.98**
11-32	0	0.5	0	0.55	0.44	**6.2**	0	0.09	0.17	0.87	0.21
>32	0	0	0	**6.37**	0	0	0	0	0	0	1.26

Slopes of less than 1 per cent correlate strongly with vegetation class 2 (trees associated with first class soils). Vegetation class 11 correlates highly with slopes between 1 and 3 per cent and to a lesser degree with slopes between 4 and 10 per cent. The results for the two steeper slope classes are low, with many vegetation types not represented, though this may be that the original data did not cover areas where there were many high slopes.

Table 4.15: Composition of dominant vegetation by slope class

Slope (%)	Dominant vegetation	Vegetation class
<1	Salmon gum, jam, morrel, mallee, scrub, box poison	**2** (1223.47 ha), 1 (150.22) 11 (134.62)
1-3	Scrub, box poison, salmon gum, jam	**11** (1917.85), 2 (1777.94)
4-10	Scrub, box poison, blackboys	**11** (140.98), 10 (93.28)
11-32	Scrub, blackboys	**6** (6.2)
>32	Wandoo, mallee, mallet, morrel	**4** (6.37)

Spatial analysis of slope and historical soil information was constructed to explore the relationship between slope and the spatial distribution of first, second and third class soils (Figure 3.26). Table 4.16 shows these relationships.

Table 4.16: *Landclass* soil classes with slope classes (bold indicates the most dominant soil class)

Slope class	Soil class (ha)		
(%)	1	2	3
<1	**998.7**	807.81	318.78
1-3	3471.74	2566.48	**4738.68**
4-10	247.86	140.66	**561.67**
11-32	0.93	1.14	**7.29**
>32	0	**6.37**	1.26

On slopes of less than 1 per cent, soil class 1 is dominant. Table 4.16 shows that third class soils dominate areas where slope ranges between 1 and 32 per cent. Slope class greater than 32 per cent is dominated by second class soils. First class soils are distributed in areas with slopes to 10 per cent, whereas second class soils occur in all slope ranges.

4.7 Relationships between the historical layers

First class soils are highly correlated with vegetation classes 2 and 1 which are in turn highly correlated with slopes of less than 1 per cent.

Second class soils are highly correlated with vegetation classes 2 and 4 (Table 4.12). Vegetation class4 is not the dominant vegetation class in any of the slope ranges considered. Vegetation class 2 is highly correlated with slopes of less than 1 per cent, but it is also the second most dominant vegetation type in slopes ranging from 1 to 3 per cent. The 1 to 3 per cent slopes are dominated by third class soils where vegetation class 2 has one of the lowest occurrences.

Third class soils are highly correlated with vegetation class 11, which in turn is highly correlated with slopes between 1 and 3 per cent. Slopes from 1 to 3 per cent are highly correlated with soil class 3 (Table 4.16)

Slopes between 4 and 10 per cent occur most frequently in third class soils, and soils in these slopes are dominated by vegetation classes 10 and 11.

From these analyses a map of historical vegetation was derived for the catchment, using the following rules:

1. If (slope <1 per cent) and (soils = first class) then vegetation = class 1 and 2
2. If (slope ≤1 per cent and ≤3 per cent) and (soils = third class) then vegetation = class 11
3. If (slope ≤4 per cent and ≤32 per cent) then vegetation = class 9, 10 and 11.
4. If (soils = third class) then vegetation = class 9, 10 and 11.
5. If (slope ≤1 per cent and ≤3) and (soils = first class), then vegetation =class 2
6. If (slope ≤3 per cent) and (soils = second class) then vegetation = class 2

The predicted historical vegetation maps are Figure 4.9 (*landclass*/slope intersection) and Figure 4.10 (reconstructed soil/slope intersection).

4.8 Redefined classes of vegetation and slope

When vegetation classes 3 to 8 were recoded as class 3, and 9 to 10 as class 4 the relationships with the soil classes are closer to what was expected (Table 4.17). As before, first class soils were dominated by vegetation classes 1 and 2. Second class soils were dominated by vegetation class 3 (closely followed by vegetation class 2) composed of trees and woodlands. Vegetation class 2, which is also dominant in second class soils, contains some of the same tree species that make up class 3. Third class soils were dominated by vegetation class 4, which according to the historical surveys is c commercially useless.

Table 4.17: Reclassified historical vegetation and historical soil class

	Vegetation class (ha)			
Soil class	1	2	3	4
1	765.2	**2101.3**	327.4	16.7
2	391.6	965.5	**1060.6**	90.2
3	9	8.4	851.5	**3045.9**

Table 4.18: Composition of dominant vegetation by soil class

Soil class	Dominant vegetation	Vegetation class (ha)
1	Salmon gum, jam, morrel, mallee	**2** (2101.3), 1 (765.2)
2	Salmon gum, jam, wandoo, mallee, mallet, morrel, stoney poison, sheoak, sandplain, box poison	**3** (1060.6), 2 (965.5)
3	Scrub, box and prickly poison, York Road poison, blackboys, mallee, wandoo, mallet, morrel, stoney poison, sheoak, sandplain	**4** (3045.9), 3 (851.5)

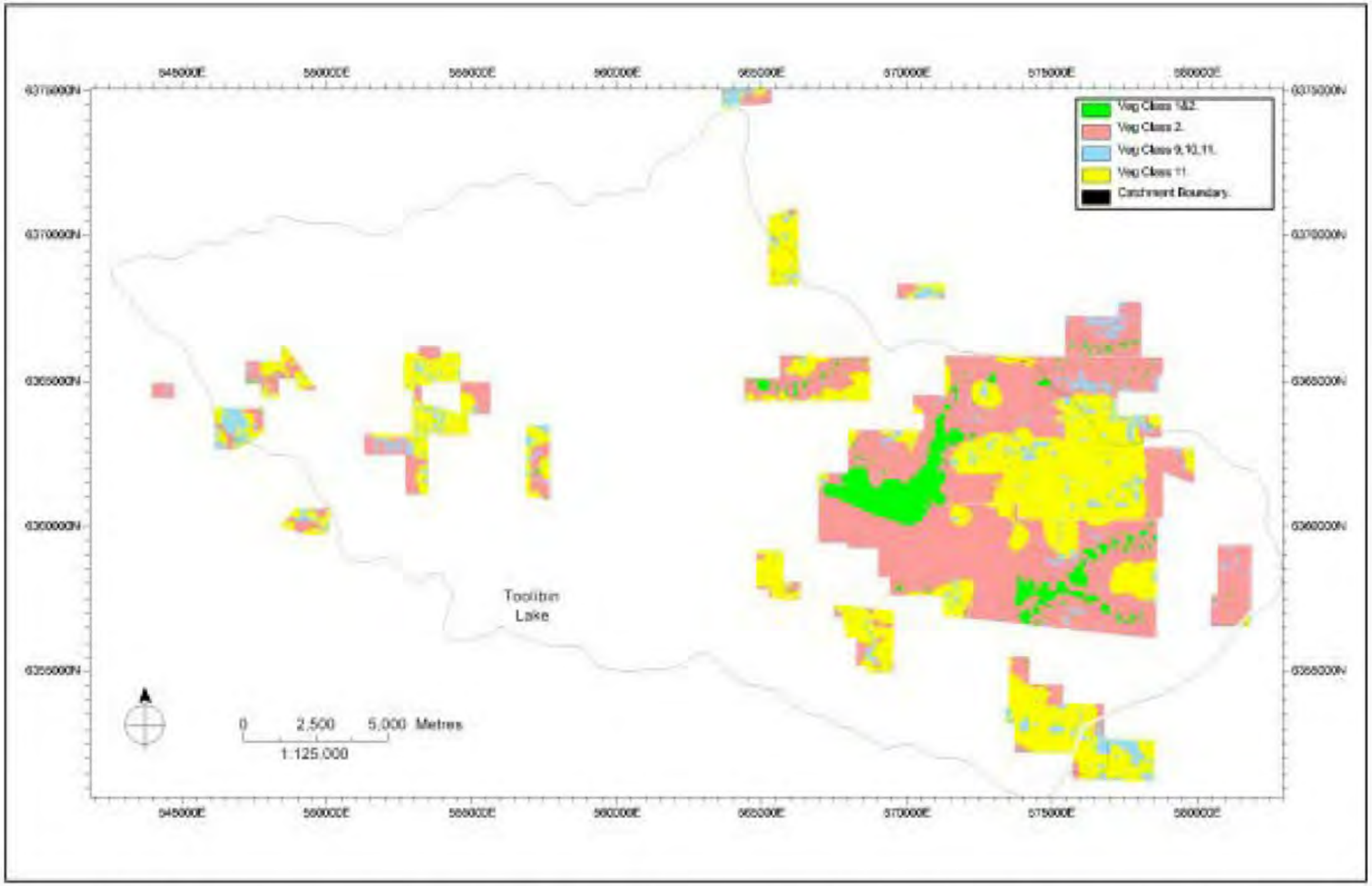


Figure 4.9: Predicted vegetation based on first set of rules - applied to landclass soils and slope (5 classes) using original 11 vegetation classes

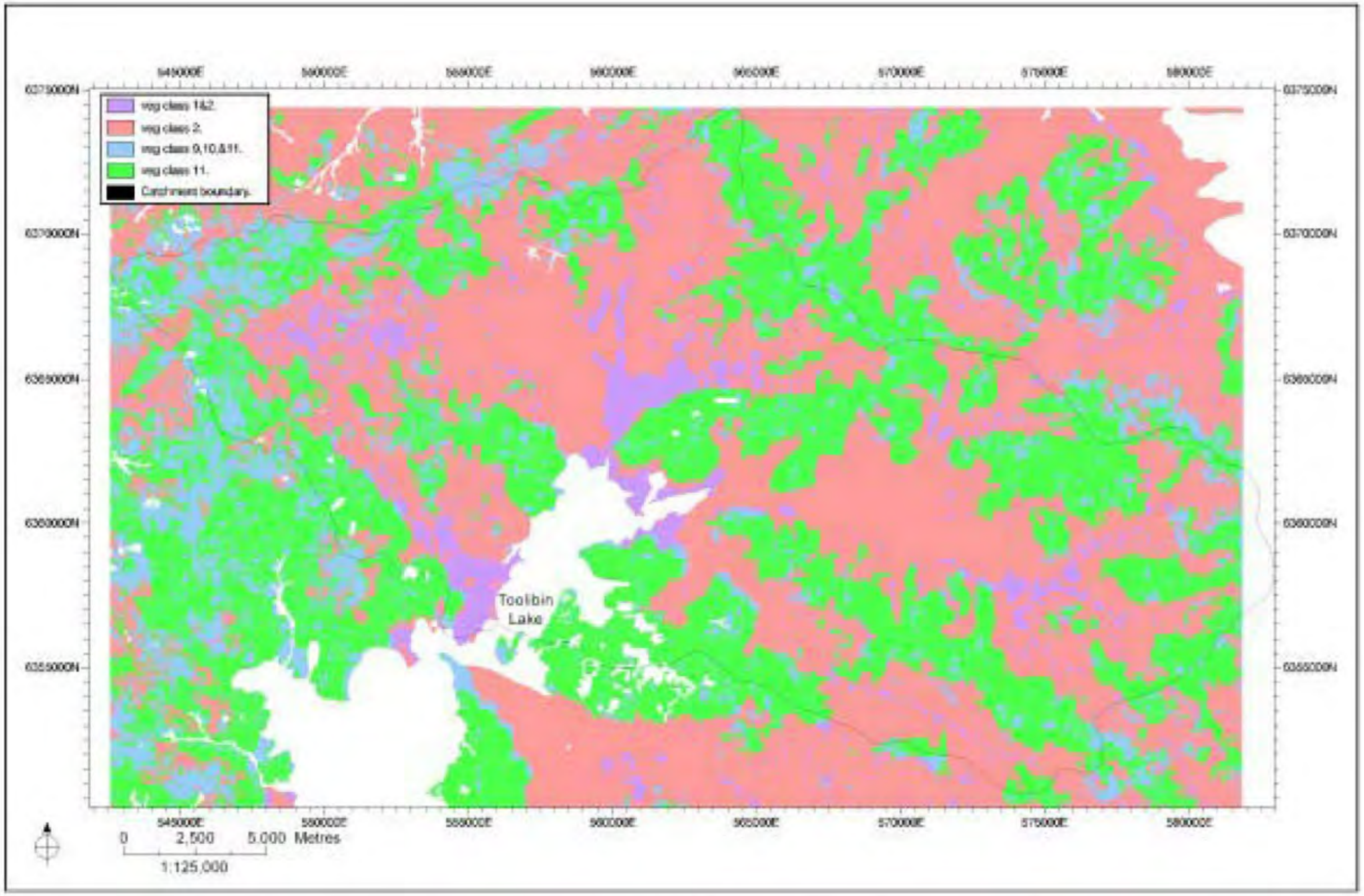


Figure 4.10: Predicted vegetation based on first set of rules - applied to reconstructed soils and slope (5 classes) using original 11 vegetation classes

Table 4.19: Reclassed historical vegetation and reclassed slopes

	Vegetation dass (ha)			
Slope class (per cent)	1	2	3	4
<1	150.22	**1223.47**	134.15	179.7
1-3	982.23	*1777.94*	*1705.8*	**2609.36**
>3	38.4	79.84	*261.39*	**276.87**

Using the reclassed slope and reclassed historical vegetation correlations (Tables 4.16, 4.17 and 4.19) it could be inferred that for the historical vegetation derived layer the following rules apply:

1. If (soils = first class) and (slope <1 per cent), then vegetation = class 1 and 2
2. If (soils = first class) and (slope ≤1 and ≤3 per cent) then vegetation = class 2
3. If (soils = third class) and (slope ≤1 and ≤3 per cent) then vegetation = class 4
4. If (soils = third class) and (slope >3 per cent) then vegetation = class 3 and 4
5. If (soils = second class) and (slope ≤3 per cent) then vegetation = class 2 and 3.
6. If (slope >3 per cent) then vegetation = class 3 and 4
7. If (soils =third class) and (slope <1 per cent) then vegetation = class 3 and 4

The above rules were used to extrapolate a predicted historical vegetation coverage (Figures 4.11 and 4.12) based on Table 3.6 vegetation classes for the whole area based on the soils and slope information. This was done by combining the respective slope and soil (the reconstructed soils in Figure 3.18 and the *landclass* historical soils in Figure 3.8) layers and recoding all the classes according to the 'rules'. As suggested by the number of rules in which it is represented, vegetation class 2 is dominant (salmon gum, jam -dominance of trees associated with first class soils), it occurs singly or with vegetation class 2 or 3 (Table 3.6). It should be noted that the composition of vegetation class 1 and 2, that Rule 1 is based on, was dominated by Vegetation class 2 (89 per cent).

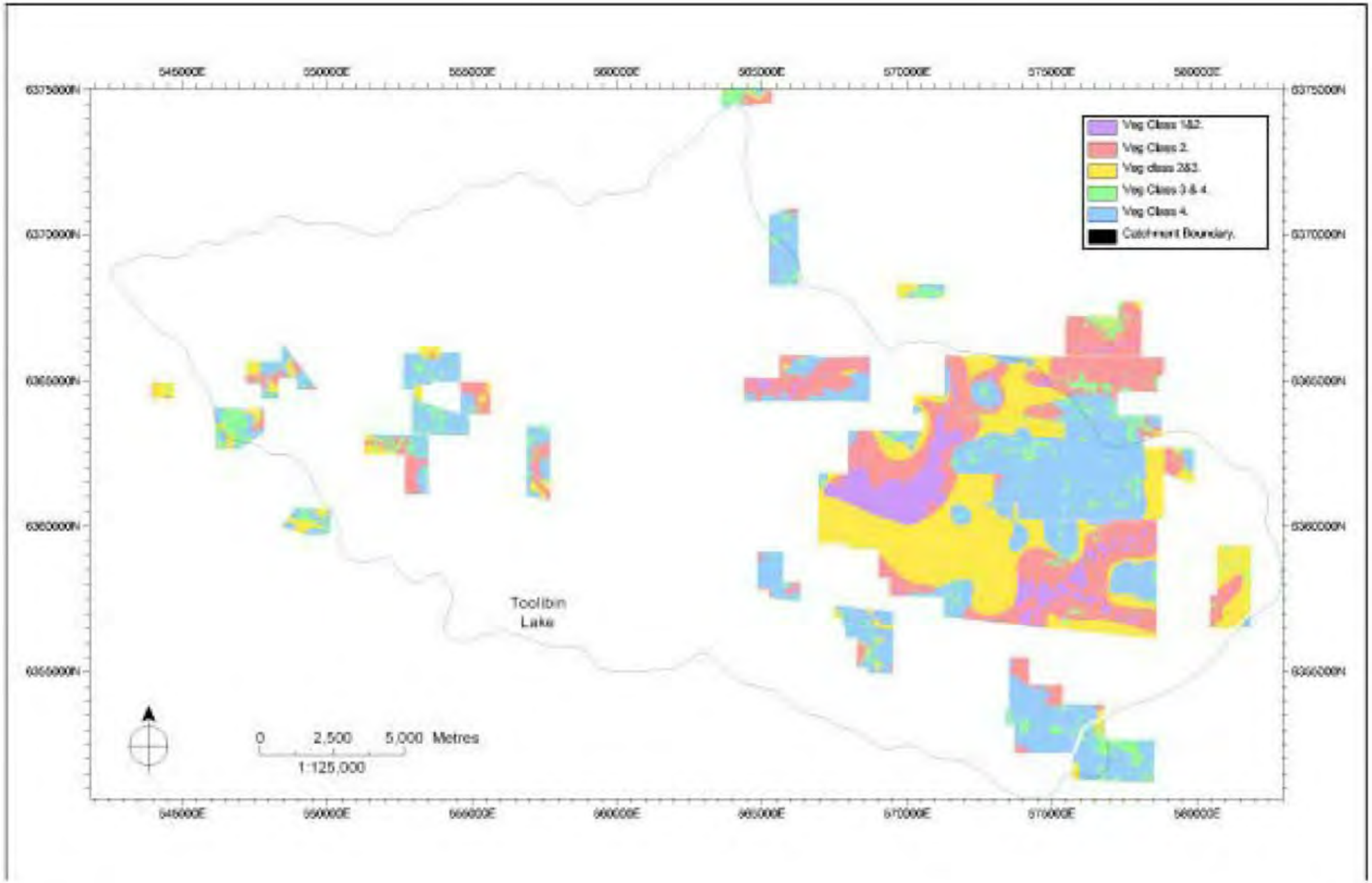


Figure 4.11: Predicted vegetation based on second set of rules - applied to landclass soils and slope (3 classes) using classified vegetation classes (4 classes)

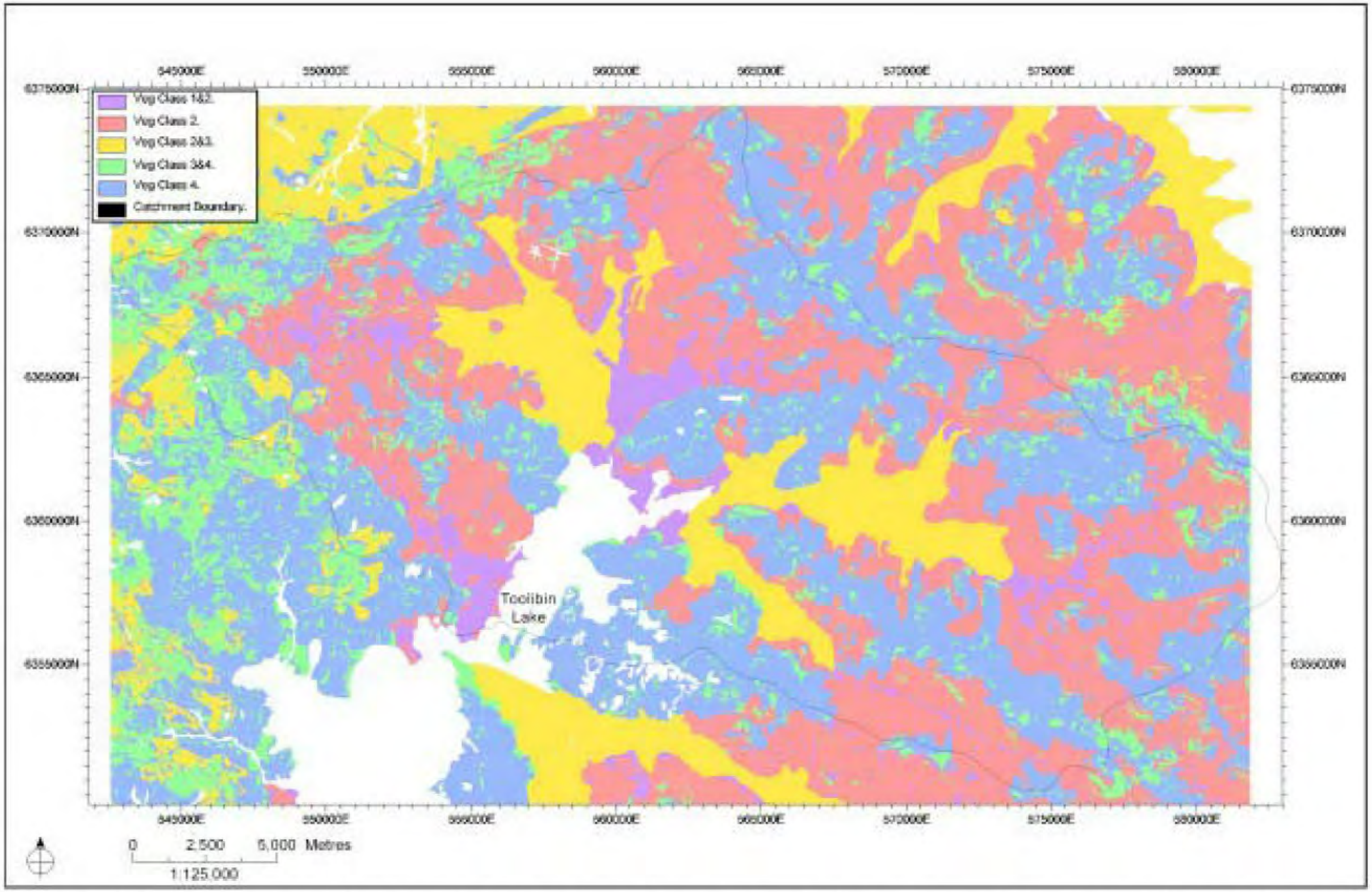


Figure 4.12: Predicted vegetation based on second set of rules - applied to reconstructed soils and slope (3 classes) using classified vegetation classes (4 classes)

5. References

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6. Appendix

Table 6.1: 1962 aerial photographs, root mean square, number of points and degrees of freedom

Photo number	*RMS (SE) used in mosaic*	*Number of points*	*Degrees of freedom (DF)*
5160	1.5200	14	22
5162	1.9783	14	22
5164	1.4631	13	18
5166	1.6920	9	12
5168	0.8574	9	12
5170	1.3969	9	12
5207	1.0103	7	8
5208	1.6481	8	10
5210	1.1802	7	8
5212	1.3941	7	8
5214	2.2383	11	16
5280	1.1202	8	10
5282	0.8756	10	14
5283	0.9731	10	14
5329	1.1456	9	12
5330	1.3220	8	10
5332	1.8566	9	12
5334	2.5294	9	12
5336	2.2721	9	12

Table 6.2: 1972 aerial photographs, root mean square, number of points and degrees of freedom

Photo Number	*RMS (SE) used in Mosaic*	*Number of Points*	*Degrees of Freedom (DF)*
5063	2.0634	24	40
5064	2.8930	19	32
5065	2.4369	19	32
5066	1.1110	12	18
5067	2.2796	10	14
5069	1.9379	19	28
5096	0.5031	5	4
5098	1.8660	18	26
5100	2.3252	9	12
5102	2.0107	22	38
5104	1.7915	11	14
5106	2.4326	9	12
5107	1.5670	10	14
5144	2.1991	17	28
5146	2.5401	24	38
5148	2.500	26	40
5150	1.9888	19	32
5152	2.6035	11	16
5189	2.3938	11	16
5191	1.2824	9	12
5192	2.1353	15	24

Table 6.3: 1983 aerial photographs, root mean square, number of points and degrees of freedom

Photo Number	*RMS (SE) used in Mosaic*	*Number of Points*	*Degrees of Freedom (DF)*
5214	1.3888	8	10
5216	1.4959	7	8
5218	1.3038	10	14
5220	1.9102	9	12
5251	1.3394	12	18
5252	2.2811	12	18
5254	1.1950	8	10
5256	1.7229	9	12
5258	2.6588	9	12
5260	2.2723	11	16
5283	2.5986	13	20
5285	1.8621	17	28
5287	2.0285	15	24
5289	2.0255	10	14
5290	2.2701	12	18
5326	1.3560	8	10
5327	1.8990	9	12
5328	1.7002	9	12

Table 6.4: Abbreviations used in Figure 3.6 and Table 6.5

Abbreviation used in text	Common name	Scientific name
Acacacum	Jam	*Acacia acuminata*
Allocamp	Tamma	*Allocasuarina campestris*
Bankspha		*Banksia sphaerocephalus*
Bosspp.		*Bossiaea* sp.
Casuhueg	Rock sheoak	*Casuarina huegeliana*
Dryaarma		*Dryandra armata*
Perielip		*Pericalymma elipticum*
YG	York gum	*Eucalyptus loxophleba*
SG	Salmon gum	*Eucalyptus salmonphloia*
W	Wandoo	*Eucalyptus wandoo*

Table 6.5: Description of vegetation at each survey site

Mslink	Patch	General description	Dominant stratum	Emergents	Second stratum	Ground layer	Condition
251		York gum					
252		York gum					
253	400a	York gum	York gum to 18 m - 35%			Grassy	Poor - unfenced, open to grazing, weedy
254	402a	Revegetation (narrow strip)	Revegetation - mixed Euca spp., some pine	Clump of original mallee between 402e and S end		Grassy	Revegetation
255	501b	Wandoo woodland	Open W to 12 m - 10%			Grassy	Degraded (adjacent salt scald)
256	399	York gum	York gum to 18 m - 35%			Grassy	Poor - unfenced, open to grazing, weedy
257	400	York gum	York gum to 18 m - 35%		Some wandoo and mallee on N side	Grassy	Poor - unfenced, open to grazing, weedy
258		Wandoo					
259		Wandoo					
260	501a	Wandoo woodland	Open W to 12 m - 10%			Grassy	Degraded (adjacent salt scald)
261		York gum					
262		Wandoo					
263	402b	Revegetation (narrow strip)	Revegetation - mixed Euca spp., some pine	Clump of original mallee between 402e and S end		Grassy	Revegetation
264		York gum					
265	402c	Revegetation (narrow strip)	Revegetation - mixed Euca spp., some pine	Clump of original mallee between 402e and S end		Grassy	Revegetation
266	402e	Mallee and sparse emergent wandoo	Mallee 8-10 m (some to 12m)	Sparse W to 12m	Sparse Allocamp to 2.5m	Dense grass	Poor
267	401	Mallee (very narrow strip of mature and degraded)	Mallee 8-10 m, many 3.5-4 m			Grassy	Poor - unfenced, open to grazing, weedy
268		York gum					
269	402f	Mallee and emergent York gum and wandoo	Mallee 8-10 m	Sparse York gum to 14m, sparse wandoo to 12m		Dense grass	Poor
270		Mallee					
271	402g	Revegetation	Mainly Eucaspp., some Acacacum??			Grassy	Revegetation

Mslink	Patch	General description	Dominant stratum	Emergents	Second stratum	Ground layer	Condition
272	402d	Revegetation (narrow strip)	Revegetation - mixed Eucaspp., some pine	Clump of original mallee between 402e and S end		Grassy	Revegetation
273		Mallee					
274		Mallee					
275	403	Mallee, single emergent York gum	Mallee 8-10m	TG?? to 16m	Casuhueg to 9m, sparse shrubs		Poor - degraded (Unfenced)
276	403	Mallee, single emergent York gum	Mallee 8-10m	TG to 16m	Casuhueg to 9m, sparse shrubs		Poor - degraded (Unfenced)
277	410a	Strip of mallee	Mallee to 10m	Wandoo		Dense grass	Poor (weeds)
278		York gum+wandoo					
279		rivergum + peppercorn trees					
280		eucalyptus					
281	410	Mallee, some wandoo	Mallee to 10m	Wandoo		Dense grass	Poor (weeds)
282		York gum					
283	132	York gum/Salmon gum over jam - highly degraded	York gum/salmon gum to 18 m - 2%		Jam to 7m - 5%	Dense grass, weeds	Very Poor - highly degraded with many dead trees
284		Salmon gum					
285	408a	Mixed - highly disturbed	Wandoo/York gum (some York gum mallee), some salmon gum, single mallet	Sparse jam, Casuhueg		Dense grass	Poor - highly distrurbed, wood cutting, unfenced
286	406b	Open mallee and wandoo	Mallee 8-10 m, wandoo to 12m			Open weeds	Poor - unfenced, grazed by stock
287	404a	Mallee and emergent wandoo	Mallee to 10m 10-30%	Sparse wandoo to 12 m	Sparse Casuhueg to 8 m	Degraded, weedy	Poor - degraded
288	406a	York gum woodland (single wandoo)	York gum 15-18 m, minor wandoo 25%			Sparse, herbaceous weeds	Poor (used by stock, car bodies)
289		York gum					
290	404c	Mixed open heath	Heath 1-2 m, mixed species 35%		Layered low shrubs and herbs		Moderate - degraded through poor management (sheep dump)
291		Wandoo + mallee					
292	404b	Mallee and Casuhueg on laterite duricrust	Mallee to 10 m 10-30%		Sparse Casuhueg to 8 m	Degraded, weedy	Poor - degraded
Mslink	**Patch**	**General description**	**Dominant stratum**	**Emergents**	**Second stratum**	**Ground layer**	**Condition**
293		York gum/Salmon					

		gum/wandoo					
294		Salmon gum/York gum					
295		Salmon gum/York gum + Mallee + A. saligna					
296	149	York gum woodland	York gum to 16 m - 12%		Wandoo to 12 m - 2%	Bare, grassy weeds	Poor - open to grazing
297	408b	Mallee woodland	Mallee to 10 m			Dense grass	Poor
298		Wandoo + mallee					
299	404e	Wandoo woodland	W to 12 m - 10-30%, some York gum regeneration		Sparse shrubs	Grassy	Poor
300		Wandoo					
301		Wandoo					
302		Salmon gum/York gum					
303		Wandoo					
304		Wandoo					
305		mallee					
306	408b	Mallee woodland	Mallee to 10 m			Dense grass	Poor
307	408b	Mallee woodland	Mallee to 10 m			Dense grass	Poor
308	406d	Mallee with some emergent wandoo and Casuhueg	Mallee to 10 m	Sparse W to 12 m	Casuhueg 8-10 m	Open grassy weeds	Fair-Poor
309	408b	Mallee woodland	Mallee to 10 m			Dense grass	Poor
310	406d	Mallee with some emergent wandoo and Casuhueg	Mallee to 10 m	Sparse W to 12 m	Casuhueg 8-10 m	Open grassy weeds	Fair-Poor
311		Wandoo					
312		Wandoo					
313		Wandoo					
314	406c	Strip of mallee	Mallee to 10 m 30%			Open grassy weeds	Fair-Poor
315	406d	Mallee with some emergent wandoo and Casuhueg	Mallee to 10 m	Sparse W to 12 m	Casuhueg 8-10 m	Open grassy weeds	Fair-Poor
316	406d	Mallee with some emergent wandoo and Casuhueg	Mallee to 10 m	Sparse W to 12 m	Casuhueg 8-10 m	Open grassy weeds	Fair-Poor
317	406c	Strip of mallee	Mallee to 10 m - 30%			Open grassy weeds	Fair-Poor

Mslink	Patch	General description	Dominant stratum	Emergents	Second stratum	Ground layer	Condition
318	406g	Heath - Perielip	Heath - Perielip to 1.5 m - 10%		Other shrubs		Degraded remnant of formerly thicker heath
319	405c	Mallee	Mallee 8-10 m		Sparse shrubs 1.2 m		Poor, weedy and unfenced
320		Wandoo+mallee+casuarina					
321		Wandoo+mallee					
322	407	Open wandoo woodland with some York gum and mallee	W open woodland to 12 m	York gum to 15 m	Mallee patches to 10 m	Open grassy understorey	Poor (Dam in centre of patch)
323	407	Open wandoo woodland with some York gum and mallee	W open woodland to 12 m	York gum to 15 m	Mallee to 10 m	Open grassy understorey	Poor (Dam in centre of patch)
324	409a	Strip of York gum/Salmon gum/wandoo running through paddocks	York gum/salmon gum to 18 m 10-30%		W to 12 m - 5%, jam to 10 m 2%, shrubs - 1%	Bare	Poor
325	133a	York gum/Salmon gum woodland, some wandoo and Mallee	York gum/salmon gum to 16-18 m		Some mallee (7-8m), some wandoo to 12m	Grassy weeds	Very Poor - many trees dead, heavily used by sheep
326	405b	York gum/wandoo open woodland, some mallee in patches	York gum/wandoo open woodland 12-18 m		Mallee 8-10m - 10%	Grassy weeds and dead wood	Poor (unfenced_
327	405b	York gum/wandoo open woodland, some mallee in patches	York gum/W open woodland 12-18 m		Mallee 8-10 m - 10%	Grassy weeds and dead wood	Poor (unfenced_
328	133b	Small spur of wandoo and sheoak on laterite gravel	Wandoo to 12m - 15%		Casuheug to 10 m - 15%	Grassy weeds	Poor - used by stock, weeds
329	409b	Thin strip of York gum/wandoo	York gum to 18 m - 10%		W to 12 m - 5%	Bare	Poor
330	134	Wandoo and sheoak open woodland	Wandoo to 12 m - 10%		Casuhueg to 8 m	Grassy weeds	Poor - used by stock, weeds
331	134	Wandoo and sheoak open woodland	Wandoo to 12 m - 10%		Casuhueg to 8 m	Grassy weeds	Poor - used by stock, weeds
332	138b	Pine					
333	138c	Tagasaste					
334	138a	Tagasaste planting					
335	138c	Tagasaste					
336	139	Tagasaste					
337		York gum + wandoo + jam					

Mslink	Patch	General description	Dominant stratum	Emergents	Second stratum	Ground layer	Condition
338	404e	Wandoo woodland	W to 12 m - 10-30%, some York gum regeneration		Sparse shrubs	Grassy	Poor
339	405a						
340	409c	Thin strip of York gum/wandoo/jam	York gum to 18 m - 10%		Wandoo to 12 m 5%, jam to 10 m - 1%, Casuhueg to 8 m - 1	Bare, grassy weeds	Poor
341		Wandoo					
342	135e	Wandoo/jam/few York gum(regen) and Casuhueg	W to 12 m - <10%, York gum (regen) to 12 m		Jam to 10 m - 5%, Casuhueg to 8m - 10%	Bare and grassy weeds	Poor (as for 135d)
343	135a	York gum/wandoo/jam with some understorey, open to grazing	York gum to 16 m - 10%	Wandoo to 12 m, jam to 10m, Casuhueg to 8m		Sparse herbs, considerable dead wood	Fair (open to grazing) but few weeds, herb layer present
344	135e	Wandoo/jam/few York gum(regen) and Casuhueg	W to 12 m - <10%, York gum(regen) to 12m		Jam to 10 m - 5%, Casuhueg to 8 m - 10%	Bare and grassy weeds	Poor (as for 135d)
345	135d	York gum/wandoo/Mallee woodland	York gum to 16 m - 10%, single salmon gum in SE corner		Wandoo to 12 m - 10%, Mallee to 10 m - 5%	Very sparse trees, bare and grassy weeds	Poor (open to grazing), no herbs or shrubs
346	135b	Thick Casuhueg / jam low woodland	Casuheug and Acacacum - 30%			Minor herbs, dead wood	Fair (open to grazing) but few weeds, herb layer present
347	135c	Salmon gum/York gum/jam/Casuhueg	Salmon gum/York gum to 16m - 10-12%		Casuhueg, Acacacum - 8-10m, 10% /mallee to 10m	Minor herbs and sparse grassy weeds	Fair-Poor (open to grazing)
348		Wandoo					
349	135f	Wandoo/jam/Casuhueg (sparse salmon gum)	W to 12 m - 10-30%	Sparse salmon gum - <1%	Jam to 10 m - 5%, Casuhueg to 8 m - 10%	Minor shrubs and herbs, grassy weeds	Fair (edge effect and gravel extraction)
350		York gum					
351	142c	York gum/jam	York gum to 18 m - 2%		Jam to 10 m - 2%	Grassy	Poor - very open canopy
352	142c	York gum/jam	York gum to 18 m - 2%		Jam to 10 m - 2%	Grassy	Poor - very open canopy
353	136	Open wandoo woodland with some mallee	Wandoo 12 m - 5%	Minor York gum	Mallee to 10 m - 5% ?	Grassy weeds	Poor - open to grazing
354		*Banksia attenuata*					
355	137	Tagasaste planting					

Mslink	Patch	General description	Dominant stratum	Emergents	Second stratum	Ground layer	Condition
356	142b	Sheoak and wandoo		Wandoo to 12m - 5%	Casuhueg to 10 m - 20%	Grassy	Fair-Poor (open to stock)
357	142a	Wandoo/sheoak and jam, sparse York gum	Wandoo to 12 m - 5%	Several York gum to 10 m - 1%	Casuhueg and jam to 10 m - 5%	Grassy	Poor - open to stock, dam present
358	142d	Jam with some revegetation			Jam to 10m - 2%	Grassy, somereveg	Revegetation
359		Periczlymma					
360	142a	Wandoo/sheoak and jam, sparse York gum	Wandoo to 12 m - 5%	Several York gum to 10m - 1%	Casuhueg and jam to 10m - 5%	Grassy	Poor - open to stock, dam present
361	148b	York gum open woodland with grassy understorey	York gum to 20 m			Bare, grassy weeds	Poor - open to stock
362	141	Pine					
363	140	Tagasaste					
364	148a	Wandoo/sheoak woodland with grassy understorey	Wandoo to 12 m - 10%		Casuhueg to 10m - 20%	Bare, grassy understorey	Poor - open to stock
365	135g	Heath/sparse emergent Casuhueg (single wandoo)	Bankspha, Dryaarma, Perielip to 1.2m - 4%	Casuhueg, Xantspp. - 1%		Low shrubs, herbs, Neur spp.	Moderate (subject to edge effect)
366	144a	Wandoo/sheoak/jam woodland	W to 12 m - 10%		Casuhueg to 8 m - 20%, jam, Perielli 1.2 m - 2%	Some weeds	Poor - open to stock (edge effect)
367	144b	Shrubland - Pericalymma	Perielli to 1.5 m			Some weeds	Poor - open to stock (edge effect)
368	146	Open wandoo with some shrubs	Wandoo to 12 m, some saplings		Sparse mixed shrubs to 1.5 m	Open grassy weeds	Fair - open to grazing
369	145	Open wandoo with some understorey shrubs	Wandoo 12 m - 10%		Sparse shrubs to 1.5m (Bossspp., Perispp.)	Some Neur spp., minor shrubs, grassy weeds	Fair - open to grazing (edge effect)
370		Wandoo					
371	145	Open wandoo with some understorey shrubs	Wandoo 12 m - 10%		Sparse shrubs to 1.5m (Boss spp., Peri spp.)	Some Neur spp., minor shrubs, grassy weeds	Fair - open to grazing (edge effect)
372	147a	Wandoo woodland with shrub understorey	Wandoo to 12 m - 20%		Mixed shrubs and herbs to 1m - 30%	Herbs with scattered weeds	Good
373	147b	York gum/salmon gum woodland	York gum/salmon gum to 25 m - 20%		Mixed shrub understorey - 50%	Herbs with scatted weeds	Good
374		Open wandoo and mallee		Wandoo to 12m - 5%	Mallee to 8m - 20%, some shrubs		Good
375	147d	Open wandoo and mallee		Wandoo to 12m - 5%	Mallee to 8m - 20%, some shrubs		Good

376	147c	York/salmon gum woodland	York/salmon gum to 25 m - 20%		Mixed shrub understorey - 50%	Herbs with scattered weeds	Good