A Study of the Land In the Catchment of the Gippsland Lakes

TC-17

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FOREWORD

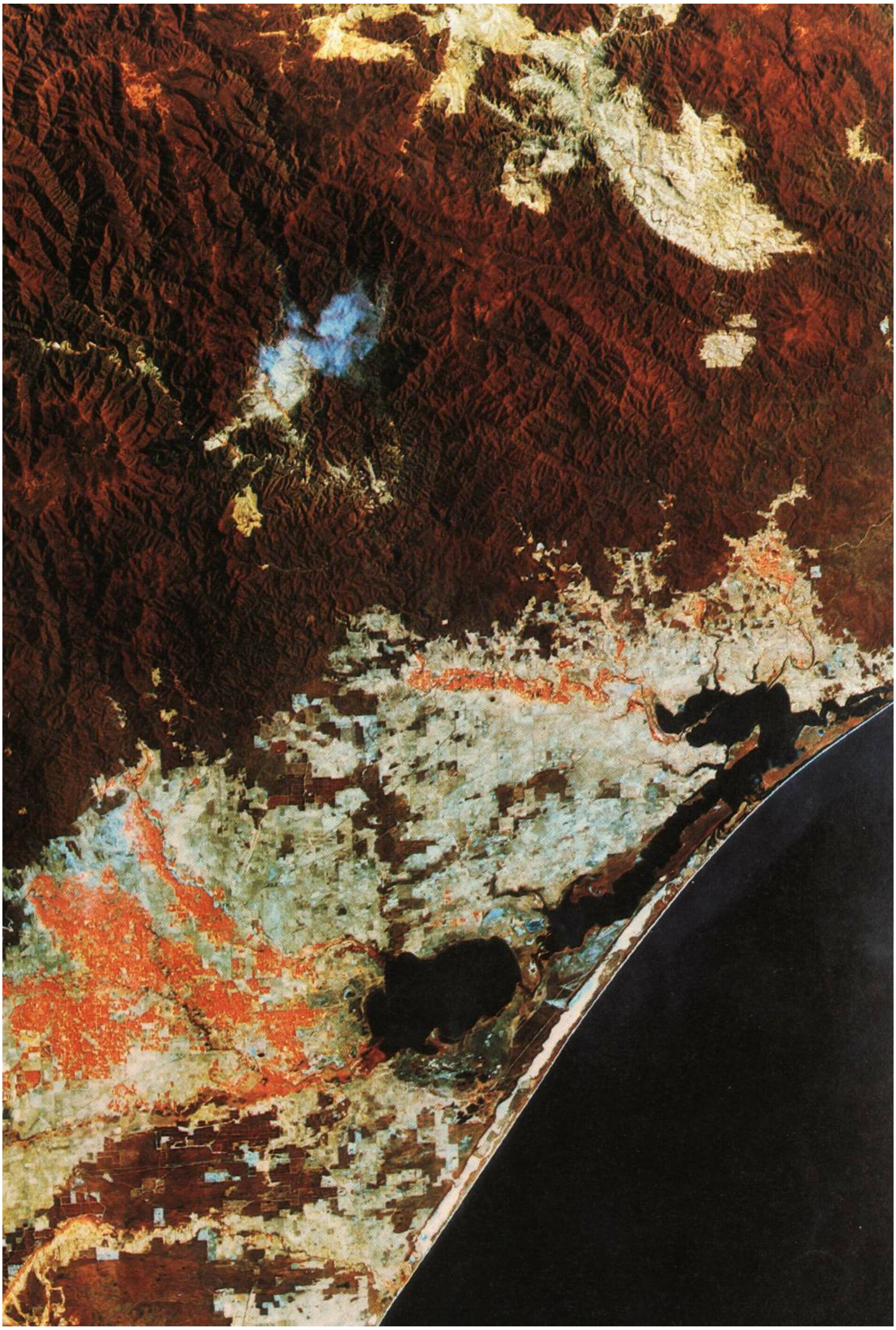
Land provides many of our material and aesthetic needs. It is conserved when management maintains and improves the productive capacity of soils without detriment to adjacent lands, waters or other resources. It deteriorates when the soil's physical, chemical and biological condition is impaired. Processes of soil deterioration can take many forms such as erosion, salting, compaction, loss of humus, leaching of nutrients, landsliding and water-logging.

Productive capacity and susceptibility to deterioration vary from one land type to another depending on the inherent land characteristics and processes and their interrelationships. Furthermore, processes in a land type can lead to off-site effects.

To develop and apply sound land management we need to recognise land types and understand the processes within them and the effect on these processes of different management practices. Systems of land classification which integrate data on climate, geological material, land form, soil and native vegetation are required. The units of classification used in this survey of the Gippsland Lakes Catchment are land systems and land components. The broadest mapping units are land systems which have been grouped into geomorphic provinces according to dominant landscape development processes. Although land systems are mapped on broad scale, descriptions of the land components within them are relatively detailed and provide information on factor affecting production, susceptibility to processes of soil deterioration and management.

This survey is one of a series designed to provide a broad initial coverage of the State of Victoria. The purpose is to map, describe and evaluate the bio-physical nature of the land as basic information needed to develop sound management systems under a variety of uses. The information can be used for regional planning and it provides a systematic background for detailed local investigation such as land capability assessment for specific uses.

The surveys have evolved from principles put forward by Downes (1949), Christian and Stewart (1953), Costin (1954), Gibbons and Downs (1964), Gibbons and Haans (1976) and others.



False colour scene of the study area, recorded from satellite on 31 December 1972.

SUMMARY

The study area of 20,600 sq km comprises the catchments of the streams flowing into the Gippsland Lakes. The area can be divided into two major physiographic regions: the uplands, which consists of the East Victorian and the South Victorian uplands, and the lowlands. Palaeozoic rocks of the uplands were subjected to extensive plantation and deep weathering during the Mesozoic. During the Tertiary stripping of the Mesozoic surface occurred and successive pulses of uplift led to the formation of at least two younger paleo-surfaces, parts of which still remain. Brown coal deposits formed on the lowlands and oil deposits developed offshore while limestones were laid down near the coast. Valley floors of basic volcanics occurred throughout the area. The Plio-Pleistocene uplift produced widespread landscape rejuvenation in both the East and South Victorian Uplands, and deposition of erosion products occurred on the lowlands and offshore. Differential erosion and drainage system modifications have contributed to the development of the present land surface.

Major factors influencing the climate of the region are the easterly movement of low and high pressure systems and the development of low pressure systems off the east coast of eastern Australia. These low pressure systems increase summer rainfall towards the east, contrasting with the west and its predominantly winter incidence of precipitation. Local climatic variation results from factors such as elevation, topography and distance from the coast. The main limitations to plant growth are moisture supply in the central-eastern parts and low temperatures during winter, particularly at higher elevations where sub-alpine to alpine conditions prevail.

Broad relationships between soil development and geomorphic history, lithology, climate and ecological conditions can be recognised. Uniformly-textured soils and gradational profiles with little differentiation, are typical of young, highly sorted sediments and of geomorphological active environments. Consequently these soils characterize coastal and lacustine sands, other Holocene sediments and the mounts and steep hillslopes. They also occur where water-logging and low temperature inhibit differentiation, for example in terrace depressions and in the alpine and sub-alpine zone. Organic soils also occur in these environments. Highly differentiated uniform soils characterize sands of old dunes, sand sheets and outwash fans. Duplex soils have developed on old stable surfaces with fine parent materials. They are widespread on the Pleistocene alluvial plains and on the low hills and gently undulating terrain.

The indigenous vegetation reflects the large range in climatic, physiographic and soil conditions. The most common structural form is open forest with height classes II and III being the most widespread. Open forest IV with ash species is found in the more humid mountain regions. In addition to open forest, extensive areas of woodland, open woodland, closed scrub, sedgeland and herbfield occur. There are also small areas of closed forest, shrubland, grassland, bog and other communities. In the uplands, the original vegetation has been modified mainly by logging, grazing and altered fire regimes. Disturbance in the lowlands has been more severe, extensive clearing having taken place to allow agricultural development. Many lowland communities, for example the E. tereticornis forests on the Pleistocene plains, have been almost entirely removed.

Eighty-four land systems are grouped into Geomorphic Provinces and Sub-provinces on the basis of current dominant landscape-forming processes. In the uplands, land systems vary mainly with lithology, topography and vegetation type, which represents a rainfall-vegetation-elevation complex. On the lowlands low systems are correlated more directly to geomorphic history. Most land systems are related to a series of alluvial fans and terraces overlain in part by sand sheets and dunes, associated with Pleistocene glacio-eustatic fluctuations. Coastal land systems relate to three barrier systems and complex patterns of erosion and sedimentation. The Baragwanath Anticline and the Western Volcanic Plateaux also influence the distribution of land types.

Land components within each land system are identified, described and evaluated in terms of limitations to biomass productivity and soil stability. Off-site effects of processes following given disturbances are also identified, particularly effects on stream flows. Several forms of soil deterioration are considered in terms of land and management factors.

Tall eucalypt forests with dense, ferny understoreys are common on protected aspects in the uplands.

ACKNOWLEDGEMENTS

Grateful acknowledgements is made to all who assisted with this report. It is only possible to mention those who have been more directly involved.

Messrs. T. I. Leslie, U. Hagel and D. Cummings were responsible for most of the laboratory analysis of soil samples; X-ray diffraction analysis of clay minerals was done by Dr. G. P. Briner of the State Chemistry Laboratory. Messrs J. N. Rowan and F. R. Gibbons provided general guidance and administrative support for the survey project. Mr Rowan also edited the report.

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Typing and word processing were ably carried out by Mrs. Joyce Simmons, Mrs. Marlene Fenton, Miss Lyn Shore and Miss Mary Marren.

Messrs. F. Gigliotti and P. Cook prepared the text for publication.

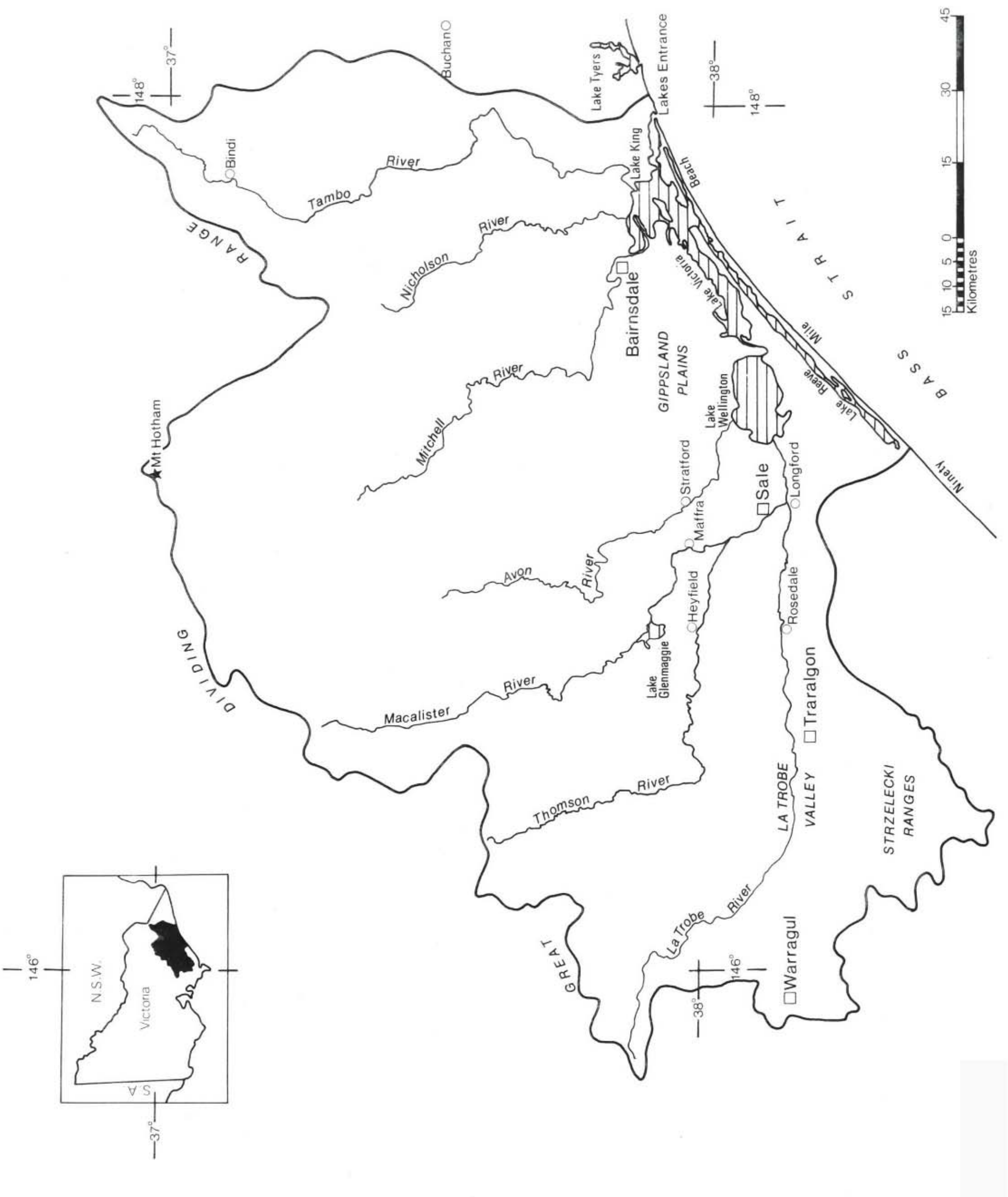


Figure 1.1 – Locality Plan

1. INTRODUCTION

The Study Area

The location of the study area and the major natural features and towns which are included, are shown in Figure 1.1.

The area consists of the catchment of the streams flowing into the Gippsland Lakes, the major rivers being the La Trobe, Thomson, Avon, Macalister, Mitchell, Nicholson and Tambo. The total area is about 20, 600 sq km or 9% of the area of Victoria.

Large parts of the Victorian Alps and the Strzelecki Ranges are included, as well as the Gippsland Plains, the La Trobe Valley, the Gippsland Lakes and much of the Ninety Mile Beach coastal zone. Elevation rises to about 1800 m in the far north , with over 15% of the area being above 900 m. the higher peaks are seasonally snow covered.

There is great variety of ecosystems due mainly to wide variation in climate, rock type, topography and in the history of earth movements, weathering and erosion.

The need for Information

Management of the Gippsland Lakes and their catchments has altered the salinity of the waters with attendant effects on aquatic life, and in places is causing shore lines and silt jetties to erode. Sport fishing as well as commercial fishing and various forms of water-based recreation are feeling the impact of these changes, while land is being lost or damaged by erosion. Subdivisions near the Lakes, intensifying agriculture, forestry, urban settlement, the mining of coal and other activities in the catchments have the potential to bring about further undesirable hydrological changes.

An understanding of the nature of the land and the types and magnitude of change that activities can cause, is vital to wise land use in the catchments and to control of the hydrological regime and water quality in the Lakes.

The Survey Approach

The technique selected for the survey was basically the standard ‘landscape’ approach (Mabbutt 1968). The mapping units are ‘land systems’. An integrated, multidisciplinary team approach was used in carrying out the basic survey using aerial photograph interpretation as a basic tool, in association with field traverse.

The identification of land systems relies on covariance between land characteristics. An assessment of the natural processes within these land systems was also undertaken to provide an understanding of the inherent properties and natural dynamics of the land, and its probable responses to management.

Details of the methodology and definitions of the mapping units are given in the introductory part of Chapter 7.

Previous Investigations in the Area

Previous surveys of individual features are mentioned in the chapters on climate, geology – geomorphology and vegetation. The following discussion concerns studies in which various physical features are integrated, that is, soil surveys, land type surveys and general resource inventories; social and economic aspects are also included in the latter.

Soil Surveys

Soil Surveys to determine the suitability of areas surrounding Heyfield, Maffra, Rosedale, Stratford and Sale for irrigation were done by Skene and Walbran (1943 and 1949) and Poutsma (1956). During the same period Skene (1951) surveyed salt affected and inundated areas on land adjoining Lakes

Wellington, Victoria and Kind, while Drake and Poutsma (1956) made a survey of the soil and agriculture potential on land contiguous to the La Trobe river between Lake Wellington and Traralgon. Gibbons *et al* (1957) identified soils in the Rosedale and Longford area and commented on their suitability for growing pines. In his classic 'Soils of Australia', Northcote (1962) mapped the soils of the study area at a scale of 1 to 2 million. Concurrently, Newell 91962) made a detailed soil survey of the Macalister Research Farm near Maffra. He followed this up in 1966 with a survey to ascertain the suitability for irrigation of land between the La Trobe and Mitchell Rivers and south of the La Trobe River.

The most recent detailed soil survey was done in 1979 by Poutsma and Turvey on lands held by APM Forests Pty. LTD. In the Traralgon and Rosedale areas.

Land type surveys

These commenced with the survey by Rowe and Downes (1960) in the catchment of the Glenmaggie Reservoir. Similar surveys have also been done by Sibley (1975) in the catchment of the Tyers River and by Nicholson (1978) in the areas adjacent to the Gippsland Lakes. D. F. Howe and T. Poutsma (unpublished data) have completed land component surveys and land capability assessments for much of the area covered by Nicholson.

Grant (1974) and Grant and Ferguson (1978) made land inventories for engineering purposes in the areas covered by the Sale and Warragul 1: 250, 000 National Topographic Series Mapsheets. The land was mapped as 'Terrain Patterns' and 'Terrain Units', similar to land system and land component mapping, but with an engineering bias.

General resource inventories

Resource inventories incorporating data from several government departments cover much of the study area. The Central Planning Authority in 1954 and 1968, provided a comprehensive survey of physical and economic resources of the East Gippsland and West Gippsland regions. The Land Conservation Council had more recently published five resource inventories which together include the whole of the study area – South Gippsland Area district 1 (1972) and District 2 (1980), Melbourne Area (1975), Alpine Study Area (1977) and Gippsland Lakes Hinterland Area (1982).

2. CLIMATE

D. A. O'Beirne

Major Features of the Climate

This section is based mainly on data from the Bureau of Meteorology, in particular data published in a report on the climate of the Gippsland Lakes catchments (1976). Additional information gathered during the survey and from other sources has also been included.

Climatic records are much more comprehensive, in terms of both the parameters measured and the number of areas at which measurements are made, in the lowlands than in the uplands. As there is a dearth of climatic measurements over the uplands and adjacent foothill, much of the climatic conditions over these areas must be inferred from elevation, topography and native vegetation.

Records for the lowlands are sufficient for analysis of rainfall and for broad description of other climatic parameters.

General discussion

Major factors influencing the climate of the region are the easterly movement of low and high pressure systems and the development of low pressure systems off the east coast of southern Australia. These low pressure systems increase summer rainfall towards the east, contrasting with the west with its predominantly winter incidence of precipitation.

Local variation results from factors such as elevation, topography and distance from the coast.

The suitability of the climate for plant growth varies across the region, the main limitations being moisture supply in the central-eastern parts and low temperatures during winter, particularly at higher elevations where sub-alpine to alpine conditions prevail.

Precipitation

Mean annual precipitation

Mean annual precipitation varies considerablly, the uplands often receiving three times more precipitation than the lowlands. (Figure 2.1).

In the uplands, most precipitation from the prevailing westerly airstreams falls on upper slopes and on the windward lower slopes so that low lee slopes tend to be rain shadow areas. Field observation, and to some extent the isohyets of Figure 2.1, indicate that major rain shadow areas exist in the Macalister and Wonnangatta Rivers.

The most extensive rain shadow in the lowlands occurs between Traralgon and Bairnsdale in the lee of the Strzelecki Ranges and the Haunted Hills.

Figure 2.2 depicts moisture regimes interpreted from Landsat imagery. These regimes were mapped by distinguishing bright red from red-brown colours on a computer-enhanced false-colour image of the region in early summer (December, 1972). The colour differences are caused by variation in the amount of infra-red radiation reflected by the vegetation. In the timbered uplands, the greater infra-red reflectance (bright red colours) is indicative of high leaf cover and possibly the presence of non-sclerophyllous species and hence of a more humid climate. In the lowlands, however, colour differences associated with various moisture levels are related not only to climate but also to land use and management, for example the irrigation of pastures.

The spectral approach for estimating general rainfall trends in the mountains seems just as valid as the extrapolation of isohyets based on scarce data. Greater precision could be achieved using satellite imagery taken at selected times in the seasonal cycle.

Seasonal distribution

Mean monthly precipitation at selected stations (Figure 2.3) indicates the effect of elevation on seasonal distribution. Precipitation in the higher country is generally much greater in winter than in summer, with much of the winter precipitation falling as snow. The lowlands have a more uniform distribution with maximum rainfall often occurring in the spring months; winter rainfalls is reduced due to the influence of high land masses to the north, south and west.

Hail and snow

Hail is produced by cold southerly air streams, usually in winter and spring, and by intense convection currents associated with thunderstorms in summer. Statistical data on hailstorms however, are difficult to obtain as storms are usually localised.

Elevation largely determines the occurrence of snow. Above 600 m snow falls frequently in winter. Above 1800 m there is usually snow cover from June to September with most falls between April and November.

The broad trend of increased snow with increasing elevations is modified by vegetation type and aspect which influence snow accumulation and melt. Areas of *Eucalyptus pauciflora* can accumulate some 50-100% more snow and can extend the snowmelt period up to 2 months. Leeward slopes receive up to twice as much snow as adjacent windward slopes and can retain it several weeks longer (Costin 1961).

Although hail and snow occur frequently in some areas, their contribution to precipitation is relatively small. Over the whole catchment, rainfall accounts for 98% of precipitation with snowfalls in the uplands accounting for the remaining 2%.

Accurate estimates of the effect of snowmelt on the hydrology of the catchments cannot be made due to lack of satisfactory analytical techniques. It seems, however, that snowmelt is too slow to be a major factor in flooding of the lowlands (Bureau of Meteorology 1976).

Rainfall duration and intensity

Rainfall duration and intensity are major factors affecting the risks of flooding and erosion.

Measurements of maximum storm intensities are not available. Table 2.1 however, gives some data on the frequency of heavy falls.

Generally, heavy rain is most likely during summer and early autumn when the atmosphere is warmer and capable of holding more water vapour than during the cooler months. The Strzelecki and Baw Baw Ranges, however, are subject to major storms throughout the year resulting in occasional major floods across the flood plain of the La Trobe River. The most significant flooding occurs in the Sale-Maffra area where the Macalister, Thomson and La Trobe Rivers converge.

Temperature

Although the catchment is not well served with temperature recording stations, especially in the mountainous areas, the data available (Table 2.2 and Table 2.3) can be used to derived broad trends.

Temperatures generally decrease with increasing elevation and are less extreme near the coast due to the moderating effect of the sea. These effects can be seen by comparing mean minimum summer temperatures for Aberfeldy, Sale East and Lakes Entrance; these are about 9°C, 12.5°C and 14°C respectively. During winter in the uplands, blizzard conditions with temperatures below zero may prevail for days at a time.

Within the uplands, minimum temperatures are strongly influenced by topographic features, such as valleys and smaller depressions, which channel or restrict the flow of cold air, and maximum temperatures are affected by aspect.

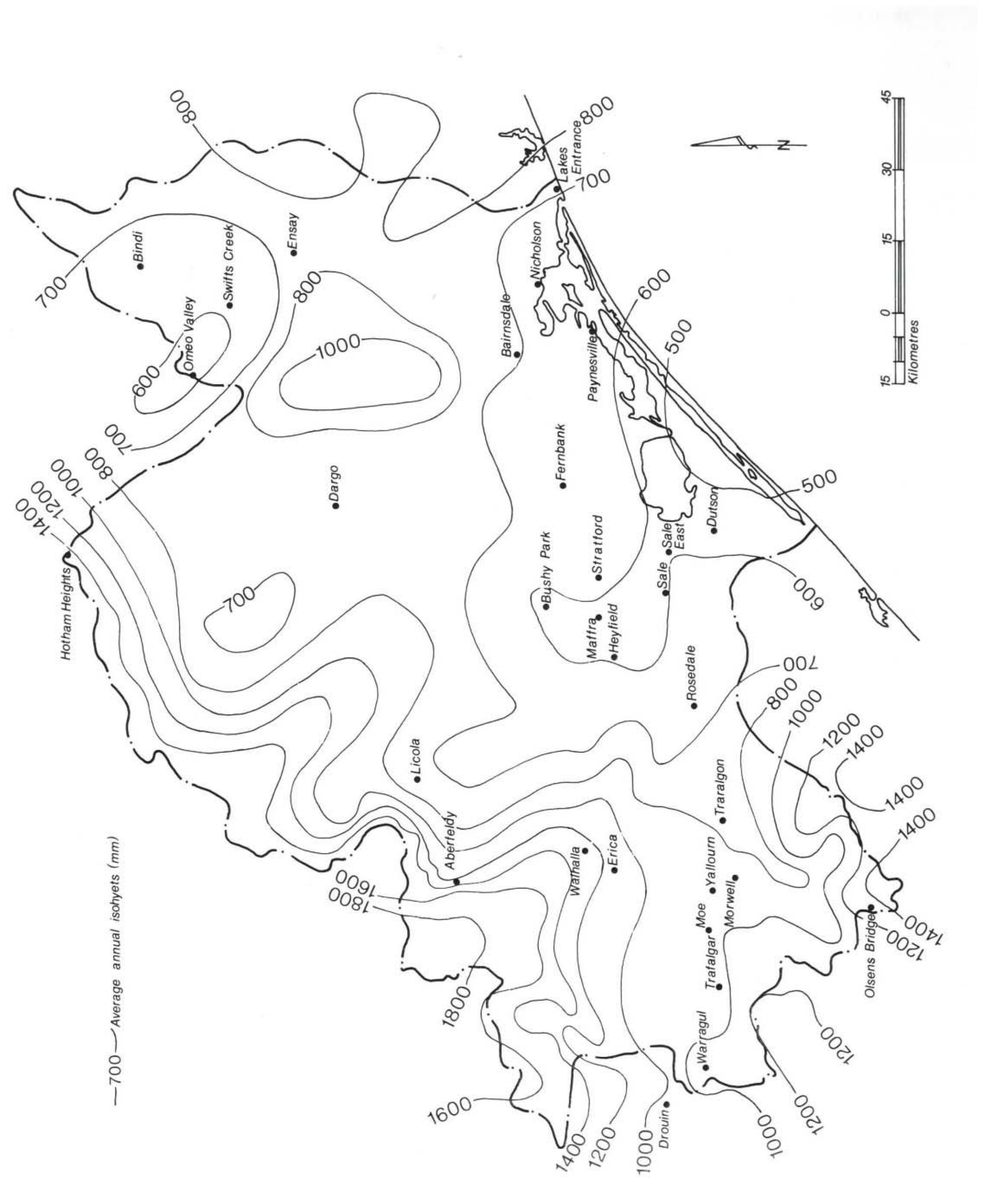


Figure 2.1 – Mean annual precipitation (Source: Bureau of Meteorology, 1976)

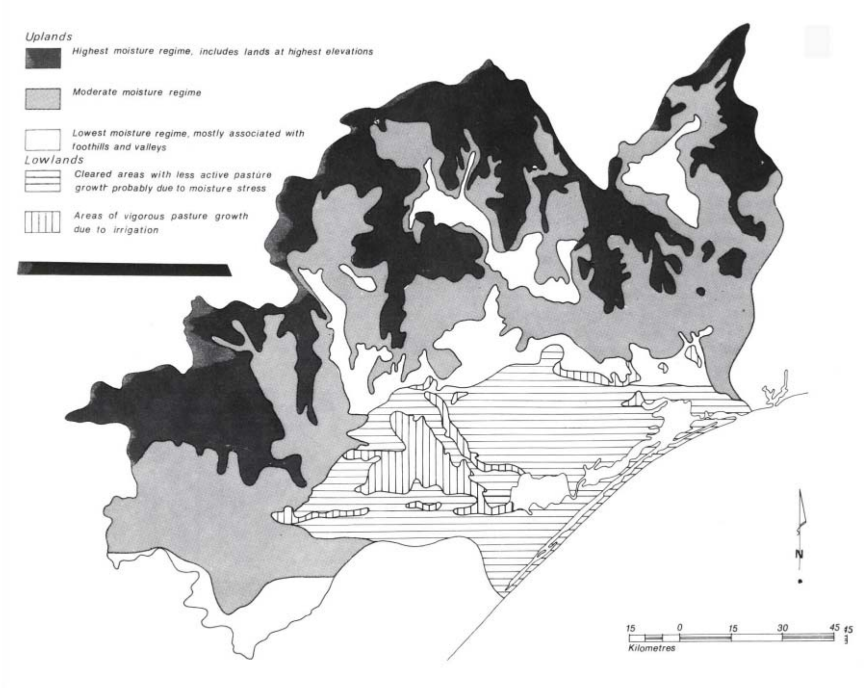


Figure 2.2 – Moisture regimes derived from Landsat imagery

Daytime winter temperatures can be quite mild in the east of the lowlands due to the Föhn effect; this occurs when moist northerly winds lose moisture over the eastern section of the East Victorian Uplands and become warm as the dry air descends.

Frost

Table 2.4 lists the mean number of frosts per annum, as indicated by screen temperatures. A light frost is arbitrarily defined as occurring when the minimum screen temperature is between 0.1°C and 2.2°C and a heavy frost when the minimum reaches 0°C or lower. Table 2.5 gives the earliest and latest dates of frost occurrence for selected localities.

Elevation and humidity are two of the major factors affecting air temperature and hence frosts. Areas at lower elevations are closer to the sea and have fewer frosts and shorter frost season. Warragul and Sale usually have 3 times as many frosts per year and Aberfeldy over 10 times as many as many as at Lakes Entrance. The frost-free period in the uplands extends from December to February, while the lower country has a frost-free period extending from October to May.

Within these broad patterns, there is local variation in the occurrence of frosts due to surface configuration, air drainage and heat conductivity of the soil. Many valleys, ravines, basins and saddles in the uplands have longer frost seasons than the surrounding terrain due to cold air drainage.

Table 2.1 – Frequency of 24 hour rainfall in excess of 75 mm

Station	No. of 24 hr falls > 75 mm in 71 years	Highest 24 hour rainfall on record (mm)	Mount of occurrence of record fall
	(1)	(2)	(3)
Lakes Entrance	27	216	Dec
Bairnsdale	15	187	Dec
Bindi	16	163	Dec
Fernbank	17	179	May
Bushy Park	13	138	May
Maffra	8	173	May
Sale	10	113	Feb
Dutson	9	97	Jan

Source: McRae (1976)

Wind

Records of wind strength and direction are available for three lowland stations only – Yallourn, Sale East and Bairnsdale. Wind direction is influenced by local topography, for example easterly and westerly winds predominate at Yallourn in the La Trobe Valley. Winds in this area are significant for the dispersal of emissions from power stations.

At Bairnsdale and Sale East, southerly and easterly summer sea breezes are quite marked. Bairnsdale often has northerly winds, probably influenced by the alignment of the Mitchell River Valley. There are no records of the local strong on-shore winds known to cause erosion along the coast.

Records are lacking also for winds at higher elevations. In the uplands, topography is known to have a strong influence on wind, for example differential heating of the land surface during the day can cause up-valley winds. Radiational cooling on clear nights and gravity cause down-valley winds.

Evaporation

Evaporation is regulated by the availability of heat (whether from incident solar radiation or from warm air), relative humidity and wind speed. Evaporation from a class A pan (evaporimeter) represents the approximate potential for water loss by evapotranspirations.

There are a few evaporimeters in the Gippsland Lakes catchments and these have been operating for only a short period of time. Figure 2.4 indicates that there is approximately a four-fold difference between summer and winter evaporation in the lowlands.

This figure also shows pan evaporation predicted by the equation of Fitzpatrick (1963). This equation is based on humidity and mean temperature but excludes the effect of wind. It closely approximates the measured evaporation except in the cooler months when it appears to be an over-estimate.

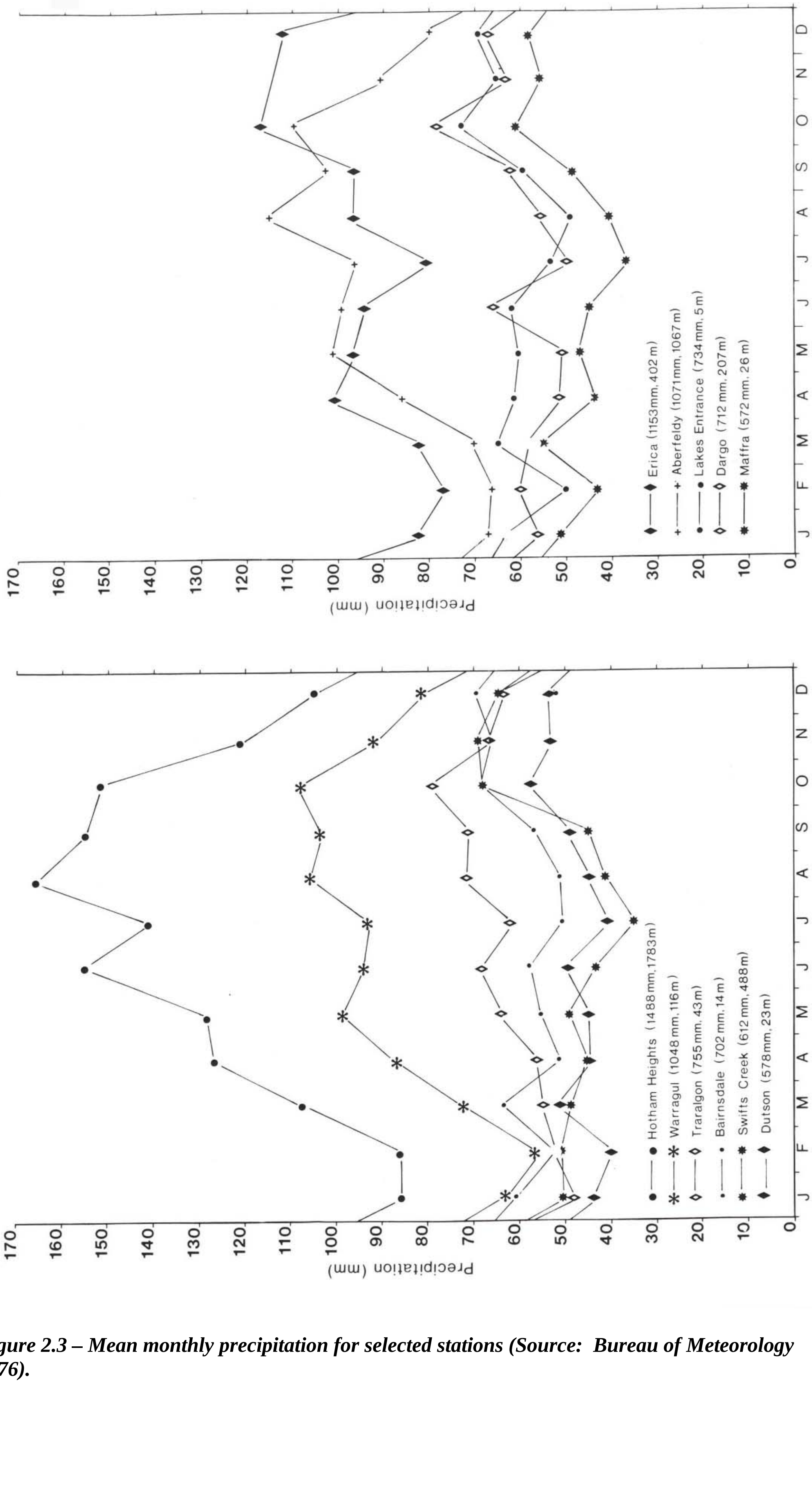


Figure 2.3 – Mean monthly precipitation for selected stations (Source: Bureau of Meteorology 1976).

Table 2.2 – Daily temperature (°C) for selected stations

Line Heading
(1) Mean Maximum temperature
(2) Highest temperature recorded
(3) 86 Percentile value of maximum temperature
(4) 14 Percentile value of maximum temperature

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Aberfeldy	(1)	20.2	20.5	16.9	14.0	9.8	6.7	6.0	6.2	9.5	12.7	14.8	18.5	13.0
	(2)	32.0	28.9	26.5	21.7	18.3	15.0	12.0	15.6	19.5	21.1	23.9	30.0	
	(3)	26.1	25.0	22.2	18.9	13.3	9.4	8.5	10.0	14.2	17.8	20.0	25.0	
	(4)	13.1	15.0	11.1	8.9	6.7	3.9	2.8	2.8	4.6	7.2	9.5	11.7	
Bairnsdale	(1)	25.1	24.5	23.6	21.1	16.9	15.5	14.3	15.4	17.2	19.6	21.6	22.9	19.9
	(2)	44.4	41.7	40.8	33.3	28.0	25.7	24.4	26.4	33.7	38.3	37.6	41.7	
	(3)	31.3	31.4	28.3	25.1	20.3	19.0	17.0	18.1	21.3	24.9	28.1	28.4	
	(4)	20.4	20.8	19.6	17.6	13.6	12.4	11.9	12.6	14.1	15.3	17.1	18.2	
Lakes Entrance	(1)	23.5	23.8	21.6	20.3	16.4	14.5	14.4	15.0	16.7	18.9	19.5	21.4	18.8
	(2)	40.7	39.5	37.2	31.7	27.0	23.9	25.0	25.6	32.0	32.4	35.6	37.8	
	(3)	29.4	29.4	25.5	23.9	19.6	17.0	17.2	18.3	21.6	24.4	23.9	28.0	
	(4)	18.9	19.8	18.3	16.7	13.3	11.8	11.7	11.9	12.8	14.7	15.1	16.7	
Sale East	(1)	25.4	25.3	23.4	20.6	16.3	14.3	13.5	14.6	16.6	19.0	21.1	23.0	19.4
	(2)	43.3	42.3	39.8	32.8	26.6	23.2	24.0	24.5	29.5	32.4	36.8	40.8	
	(3)	31.7	31.1	28.3	24.6	19.5	16.8	15.7	17.1	20.1	23.6	26.4	29.4	
	(4)	20.7	21.0	19.4	17.2	13.3	11.7	11.4	12.2	13.5	15.1	16.9	18.3	
Warragul	(1)	25.8	26.0	23.7	20.0	15.7	13.4	12.7	13.8	15.9	18.7	20.7	23.0	19.1
	(2)	41.7	42.3	38.1	31.2	26.1	20.6	22.2	23.1	26.7	31.7	36.7	38.9	
	(3)	33.0	33.1	30.0	24.6	19.3	16.0	14.9	16.7	19.9	24.6	26.5	30.1	
	(4)	19.8	20.2	18.4	15.6	12.3	11.0	10.5	11.1	12.2	13.8	15.7	16.8	

Source; Bureau of Meteorology (1976)

Table 2.3 – Daily minimum temperatures (°C) for selected stations

Line Heading
(1) Mean minimum temperature
(2) Lowest temperature recorded
(3) 86 Percentile value of maximum temperature
(4) 14 Percentile value of maximum temperature

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Aberfeldy	(1)	9.0	10.4	7.4	6.2	3.3	1.0	0.4	0.3	1.8	3.7	5.2	7.6	4.7
	(2)	1.7	2.8	0.0	-1.1	-1.7	-5.6	-5.6	-7.0	-5.0	-3.9	-1.1	0.0	
	(3)	14.3	14.4	1..2	9.4	7.2	3.3	3.3	2.8	5.5	7.8	9.2	14.3	
	(4)	4.5	6.1	3.3	3.3	0.0	-1.7	-1.7	-2.2	-2.0	0.0	1.2	2.8	
Bairnsdale	(1)	13.0	13.2	12.0	8.9	6.6	5.0	4.3	4.8	6.6	8.4	9.9	11.8	8.7
	(2)	3.9	3.9	1.1	-1.7	-3.9	-5.3	-3.3	-3.3	-3.3	0.0	1.7	2.2	
	(3)	16.7	16.8	15.8	12.8	1.6	8.9	7.2	7.7	9.6	11.5	13.3	15.3	
	(4)	9.4	9.0	8.3	5.1	2.8	1.1	1.1	1.7	2.9	4.7	6.4	7.8	
Lakes Entrance	(1)	14.2	14.9	13.0	10.9	8.2	6.1	5.3	5.8	7.1	9.1	10.4	12.2	9.8
	(2)	7.2	7.8	6.1	0.6	2.6	-0.6	-0.6	0.8	-0.6	2.2	3.1	5.6	
	(3)	17.2	17.8	15.8	13.9	11.1	8.9	7.8	8.3	9.7	12.5	13.4	15.6	
	(4)	11.1	11.3	10.0	7.9	5.6	2.8	2.4	2.9	4.4	5.8	7.2	8.9	
Sale East	(1)	12.9	13.3	11.5	8.5	6.1	4.1	3.3	4.3	5.6	7.8	9.4	11.4	8.2
	(2)	3.9	3.3	3.2	-1.7	-2.8	-4.5	-4.2	-5.6	-3.7	-1.1	1.7	2.2	
	(3)	16.6	17.2	15.3	12.2	9.7	7.9	6.6	7.6	9.0	11.4	12.8	15.1	
	(4)	9.3	9.5	7.7	4.7	2.6	0.0	-0.3	1.0	2.2	4.3	5.8	7.7	
Warragul	(1)	12.6	13.3	11.5	8.8	6.5	4.8	3.8	5.1	6.2	7.8	9.3	11.0	8.4
	(2)	3.9	3.3	1.8	-1.6	-1.1	-3.4	-3.7	-3.5	-1.6	-0.9	1.6	2.8	
	(3)	16.1	16.9	14.8	12.3	10.5	8.9	7.5	8.1	9.4	11.3	12.3	14.5	
	(4)	9.0	9.4	7.8	7.8	2.3	0.1	-0.1	1.7	2.9	4.2	6.0	7.4	

Source: Bureau of Meteorology (1976). This report also gives data for Erica State Forest, Maffra, Olsens Bridge and Yallourn.

Table 2.4 – Occurrence of frosts for selected stations as indicated by screen temperatures (Mean number of frosts per month and year

Lower frost – Screen minimum 2.2°C or lower but not as low as 0.0°C
Heavy Frost – Screen minimum 0.0DC or lower.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Aberfeldy (1970-74) – Elevation 1067m													
All Frosts	0.6	0	1.4	2.8	7.8	20.0	22.6	19.0	13.6	11.0	3.4	1.0	103.2
Light Frosts	0.6	0	1.2	2.0	4.6	8.8	7.8	7.0	6.6	7.0	2.4	1.0	49.0
Heavy Frosts	0	0	0.2	0.8	3.2	11.2	14.8	12.0	7.0	4.0	1.0	0	54.2
Lakes Entrance (Pine Hill) (1966-75) – Elevation 73m													
All Frosts	0	0	0	0.2	0	2.5	2.9	2.4	0.9	0.1	0	0	9.0
Light Frosts	0	0	0	0.2	0	2.1	2.7	2.4	0.8	0.1	0	0	8.2
Heavy Frosts	0	0	0	0.2	0	0.4	0.2	0	0.1	0	0	0	0.8
Sale East (1874-75) – Elevation 5m													
All Frosts	0	0	0	0.6	2.9	7.7	9.9	7.5	4.2	0.8	0.1	0	33.7
Light Frosts	0	0	0	0.5	2.4	4.1	5.4	4.8	3.2	0.8	0.1	0	21.3
Heavy Frosts	0	0	0	0.1	0.5	3.6	4.5	2.7	1.0	0	0	0	12.4
Warragul P.O (1962-75) – Elevation 99m													
All Frosts	0	0	0.1	0.9	3.2	6.9	7.6	4.6	2.7	1.1	0.4	0	27.5
Light Frosts	0	0	0.1	0.8	2.6	3.2	3.8	3.0	1.8	1.0	0.4	0	16.7
Heavy Frosts	0	0	0	0.1	0.6	3.7	3.8	1.6	0.9	0.1	0	0	10.8

Source: Bureau of Meteorology (1976)
This report gives data for Bairnsdale, Erica State Forest, Maffra (composite), Olsens Bridge and Yallourn.

Table 2.5 – Dates of occurrence of temperatures associated with frosts

Column (Heading)
(1) Earliest date in any year on which temperature first fell to 2.2°C (or 0.0°C)
(2) Mean difference (days) of first occurrence of 2.2DC (or 0.0DC) for median date
(3) Median date in year on which temperature first falls to 2.2DC (or 0.0DC)
(4) Median date in year on which temperature last fell to 2.2DC (or 0.0DC)
(5) Mean difference of last occurrence of 2.2DC (or 0.0DC) from median date
(6) Latest date in any year on which temperature fell to 2.2DC (or 0.0°C)
(7) Number of days between median dates of last and first occurrence of 2.2°C (frost free days)

Station	First 2.2°C			First 0.0°C			Last 0.0°C			Last 2.2°C			No of frost free days
	(1)	(2)	(3)	(1)	(2)	(3)	(4)	(5)	(6)	(4)	(5)	(6)	(7)
Aberfeldy	2 Jan	4	11 Jan	30 Mar	15	28 Apr	27 Oct	12	26 Nov	15 Dec	14	26 Dec	27
Bairnsdale	1 Feb	17	30 Apr	1 Feb	29	3 Jun	12 Aug	8	4 Sep	21 Sep	12	16 Oct	220
Erica St. Forest	23 Mar	27	5 Jun	14 May	30	16 Jul	24 Sep	40	12 Nov	7 Oct	21	12 Nov	236
Lakes Entrance	9 Apr	21	9 Jun	26 Apr	29	17 Jun	25 Jun	42	13 Sep	26 Aug	21	25 Oct	285
Maffra	5 Apr	17	5 May	15 May	18	7 Jun	18 Aug	18	26 Sep	11 Oct	17	17 Nov	206
Olsens Bridge	10 Jan	21	13 Feb	22 Mar	15	15 Apr	21 Oct	20	20 Dec	3 Oct	20	25 Dec	72
Sale East	5 Apr	17	8 May	27 Apr	16	2 Jun	26 Aug	19	4 Oct	4 Oct	18	19 Dec	216
Warragul	11 Mar	18	1 May	14 Apr	19	8 Jun	1 Sep	24	29 Oct	29 Oct	19	9 Nov	184
Yallourn S. E. C.	14 Apr	16	31 May	6 Jun	24	1 Jul	7 Aug	25	13 Sep	13 Sep	22	12 Oct	260

Source: Bureau of Meteorology (1976)

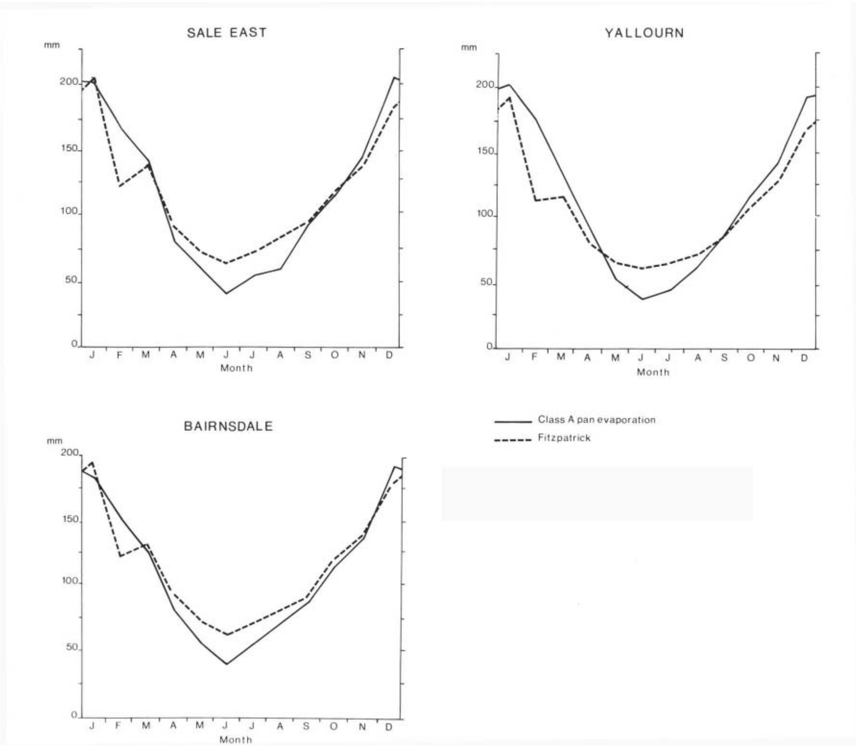


Figure 2.4 – Average monthly evaporation

Climate and Plant Growth

Climatic indices

Various indices have been devised to assess the climatic factor in plant growth, particularly under agriculture, and are usually based on seasonal rainfall and temperature regimes. Indices discussed here are limiting temperatures effective rainfall and rainfall – evapotranspiration balance.

Limiting Temperature

Assessment of a temperature regime for plant growth can be based on the assumptions that growth is severely retarded when the mean monthly temperature drops below 10°c (Trumble 1939) and effectively ceases when it falls below 7°C (Trumble 1939), or 5.5°C (Manley 1945).

Figure 2.5 indicates that temperatures are not restricting for any month near the coast, while further inland growth is restricted by low temperatures from about the beginning of June to the end of August. At high elevations, for example at Hotham Heights or Aberfeldy, growth is likely to be restricted from April to November and is probably negligible from at least June to August.

Effective rainfall

Effective rainfall is defined as the minimum amount of rain necessary to start plant growth and maintain soil moisture levels in the root zone above wilting point (Bureau of Meteorology 1976).

Table 2.6 lists, for various localities, the probability of each month receiving effective rainfall. Generally, the more elevated parts of the catchments have higher probabilities in all months than the lower country, with most upland areas being almost assured of effective rainfall in winter and spring, In the lowlands, the probabilities in winter and spring vary from 77 to 100%.

The probability of a particular period of effective rainfall can also be estimated form this table. For example a 10 month period of effective rainfall from March to December, could be expected 5 years in 10 at Maffra but 7 out of 10 years at Warragul.

Rainfall – evapotranspiration balance

Another way of estimating the period during which rainfall is adequate for plant growth is to determine the months in which rainfall exceeds potential evapotranspiration, which is the amount of moisture that can be lost by evaporation and transpiration from a fully vegetated area when soil moisture is not limiting. In the months that rainfall exceeds potential evapotranspiration, water is not limiting for plant growth.

Figure 2.5 indicates that water is not limiting for about 11 months of the year at Hotham Heights and only for about 6 months, from April to September, at Yallourn.

Non-climatic factors affecting growing season

Soil water storage

The amount of water stored in the soil available to plants affects the period for which water is limiting for growth as it influences the time taken for the soil moisture levels to reach wilting point once evapotranspiration exceeds rainfall. It depends on the amount of rainfall in excess of the depth of the rooting zone and site drainage. Site drainage in turn is influenced by factors such as slope, subsurface pans and water tables.

The effect that available water storage capacity can have is illustrated in Figure 2.6, using soil and climatic data from the Olsens Bridge district. The graphs indicate that the krasnozemic soils with around 10 mm water storage capacity in the top 50 cm are able to store sufficient water to overcome the deficit between rainfall and potential evapotranspiration in the first 2 months of the December to March period while the Brown Earths, with around 60 mm of water storage have sufficient water to overcome the deficit between rainfall and potential evapotranspiration in the first 2 months of the

December to March period while the Brown Earths, with around 60 mm of water storage have sufficient water to make up the deficit only in December. Consequently, near Olsens Bridge, there would generally be a longer growing season for the Krasnozems than for the Brown Earths.

The main reason for this difference in available water storage capacity is the much higher content of organic matter in the top 50 cm of the Krasnozem. The available water storage of soils is associated with soil pores ranging in size from 0.2 to 30 µm (1 micrometer – 1 thousandth of a millimeter). In general, soils with clay particles and especially with more organic matter have more pores in the size range. Each percent of organic matter seems to be associated with about five times more available water storage than each percent of clay. This relationship does not hold for highly compacted soils.

Table 2.6 – probability (%) of receiving at least the effective rainfall for each month

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aberfeldy	76	62	82	95	96	100	100	100	100	97	85	75
Bairnsdale	58	55	64	71	75	83	84	85	92	89	66	68
Dargo	55	63	65	70	88	91	93	95	93	92	69	70
Dutson	45	44	56	62	70	92	90	90	91	85	55	54
Erica	67	72	79	98	93	98	100	100	100	100	100	95
Lakes Entrance	63	55	74	83	84	91	96	88	98	90	70	70
Licola	54	38	61	57	97	100	100	96	96	96	85	70
Maffra	45	44	56	55	63	77	82	80	87	85	54	50
Olsens Bridge	75	75	75	92	100	100	100	100	100	100	96	83
Paynesville	57	49	68	73	80	87	87	89	89	86	63	65
Rosedale	42	45	6	69	79	93	93	96	96	91	68	55
Sale	41	45	62	65	70	90	91	93	93	87	68	55
Swifts Creek	46	67	60	60	76	86	86	91	91	94	80	63
Traralgon	39	50	62	77	90	97	98	96	98	93	95	55
Warragul	60	54	75	96	98	100	100	100	99	95	86	78
Yallourn	42	62	65	81	100	96	100	100	100	92	88	3

Source: bureau of Meteorology (1976)
Land Conservation Council (1972)

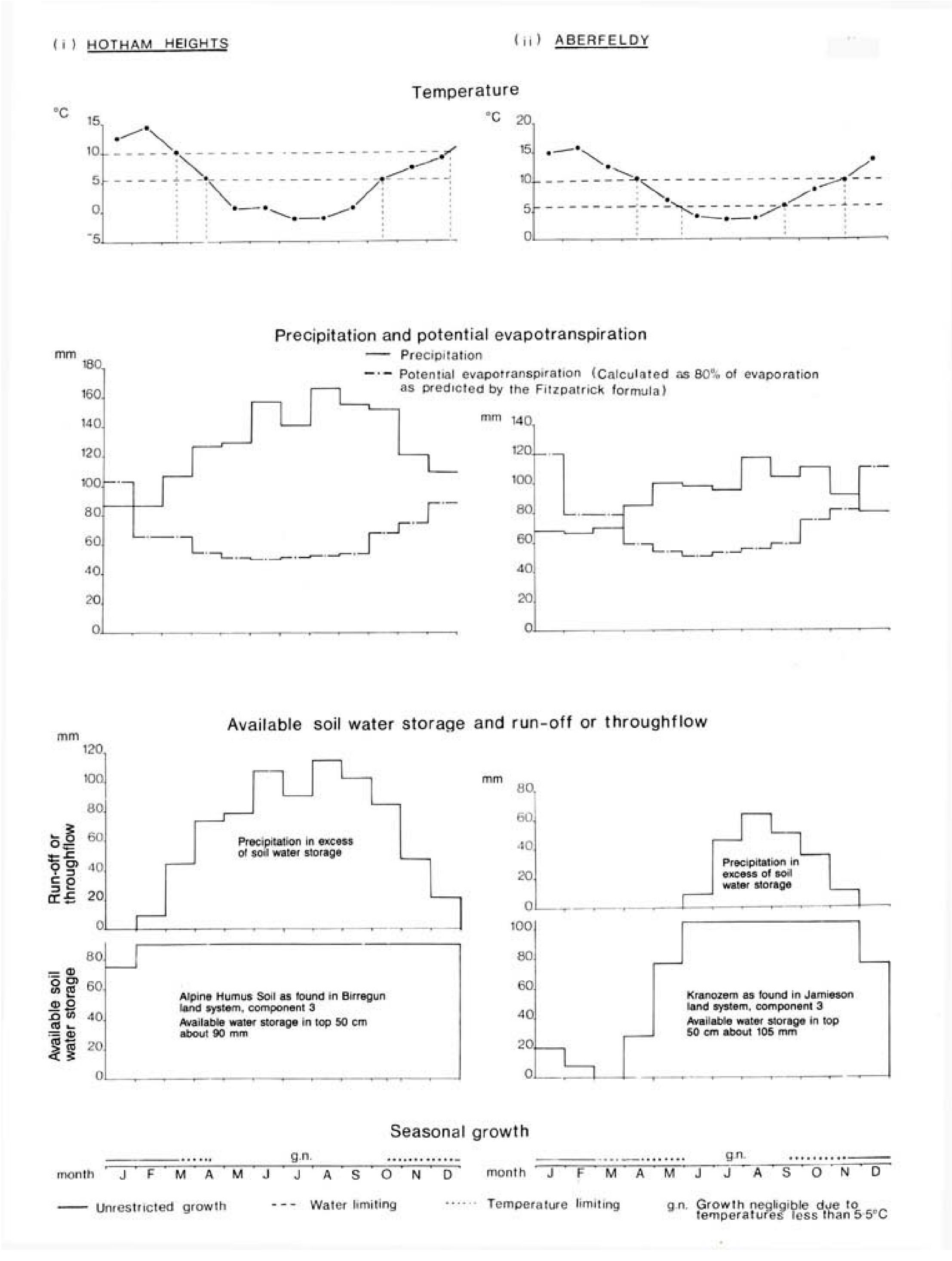
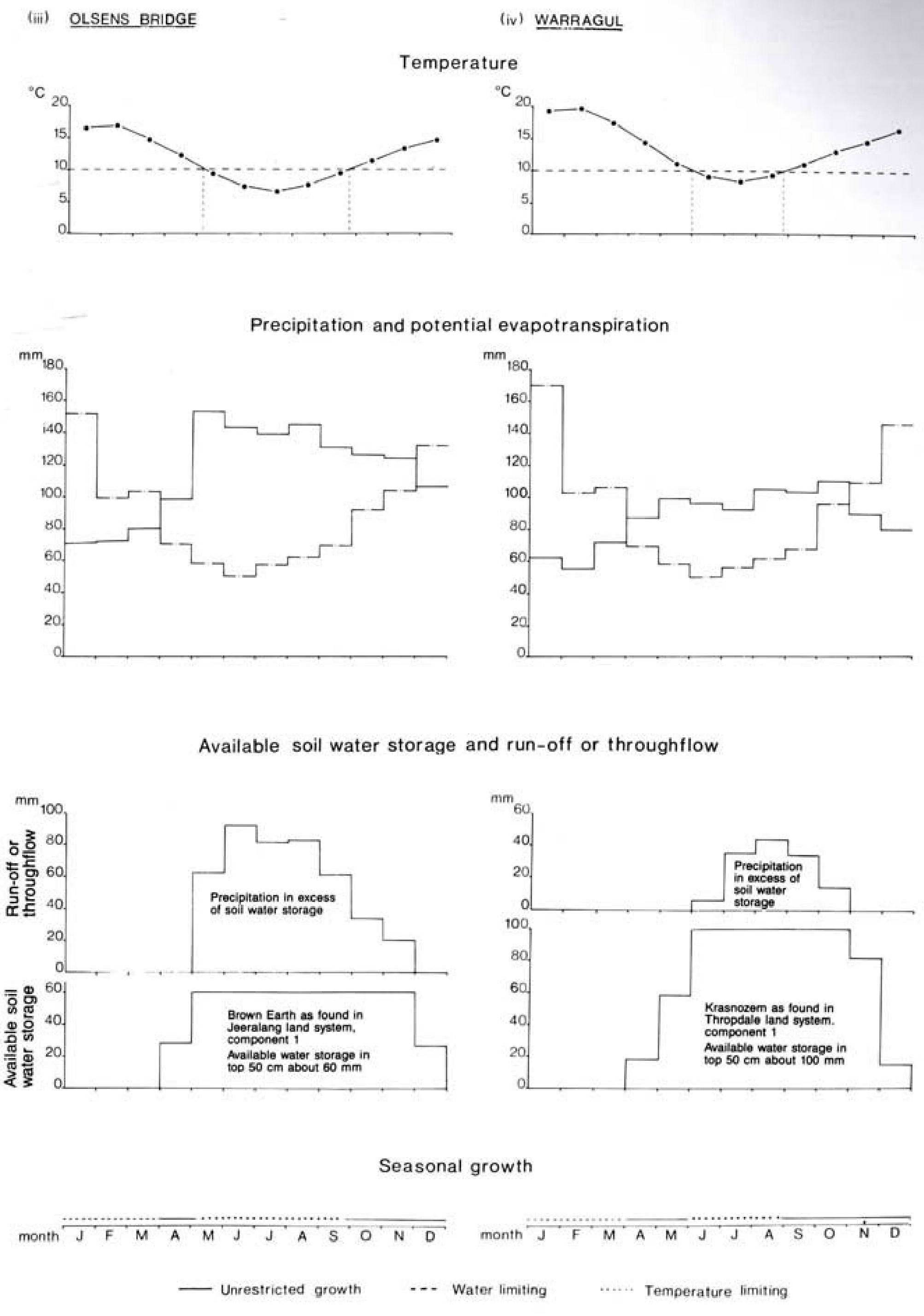


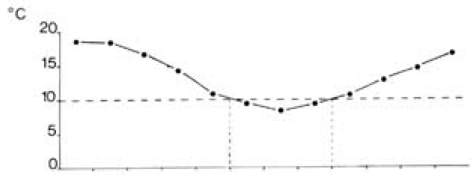
Figure 2.5 – Estimated growing seasons for 8 localities as influenced by temperature, precipitation, potential evapotranspiration and soil moisture storage.

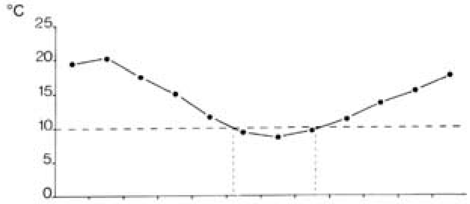

(iii) OLSENS BRIDGE
(iv) WARRAGUL
Temperature
°C
20
15
10
5
0
Precipitation and potential evapotranspiration
mm
180
160
140
120
100
80
60
40
20
0
Available soil water storage and run-off or throughflow
Run-off or throughflow
Available soil water storage
Precipitation in excess of soil water storage
Brown Earth as found in Jeeralang land system, component 1
Available water storage in top 50 cm about 60 mm
Krasnozem as found in Thropdale land system, component 1
Available water storage in top 50 cm about 100 mm
Seasonal growth
month J F M A M J J A S O N D
Unrestricted growth
Water limiting
Temperature limiting

(v) YALLOURN

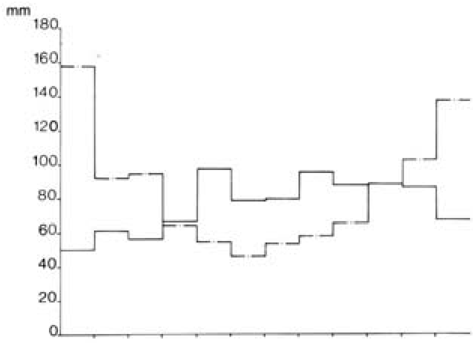
(vi) MAFFRA

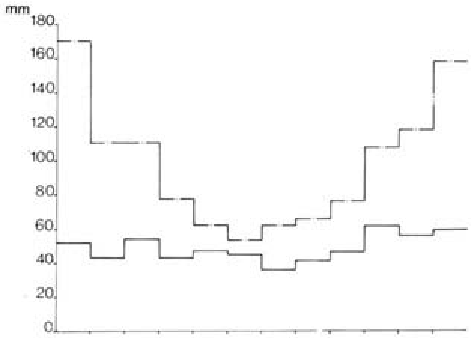
Temperature



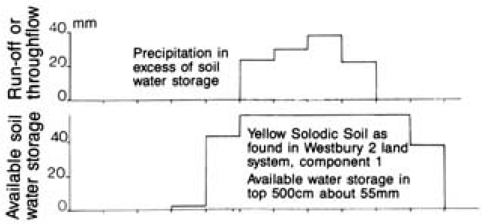


Precipitation and potential evapotranspiration



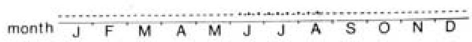


Available soil water storage and run-off or throughflow



On a mean monthly basis, there is no month when precipitation exceeds potential evapotranspiration Although storage of water may occur following heavy rain, such storage is unlikely to last into the next month

Seasonal growth

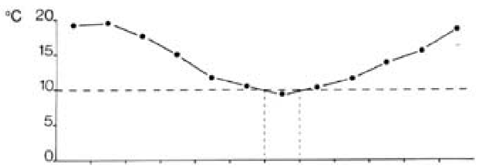


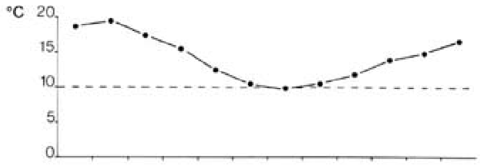
— Unrestricted growth --- Water limiting ...... Temperature limiting

(vii) BAIRNSDALE

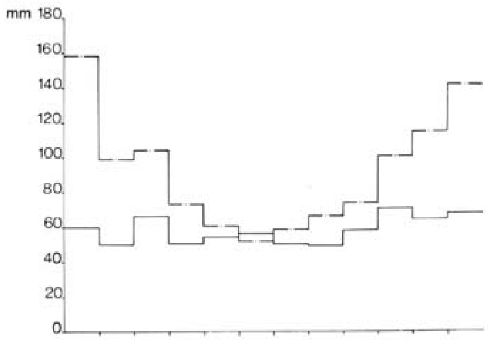
(viii) LAKES ENTRANCE

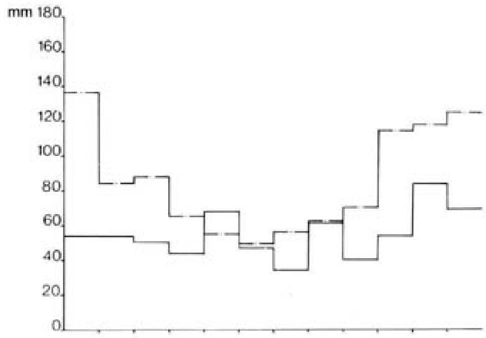
Temperature





Precipitation and potential evapotranspiration



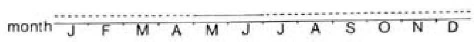


Available soil water storage and run-off or throughflow

On a mean monthly basis , June is the only month when precipitation exceeds evapotranspiration. However, the resultant moisture stored is insufficient to make up the rainfall deficit in July. Thus June is the only month during which moisture is not limiting for plant growth

On a mean monthly basis, May is the only month when precipitation exceeds potential evapotranspiration. However, the resultant moisture stored is sufficient to make up the rainfall deficit in June.

Seasonal growth



— Unrestricted growth --- Water limiting ······ Temperature limiting

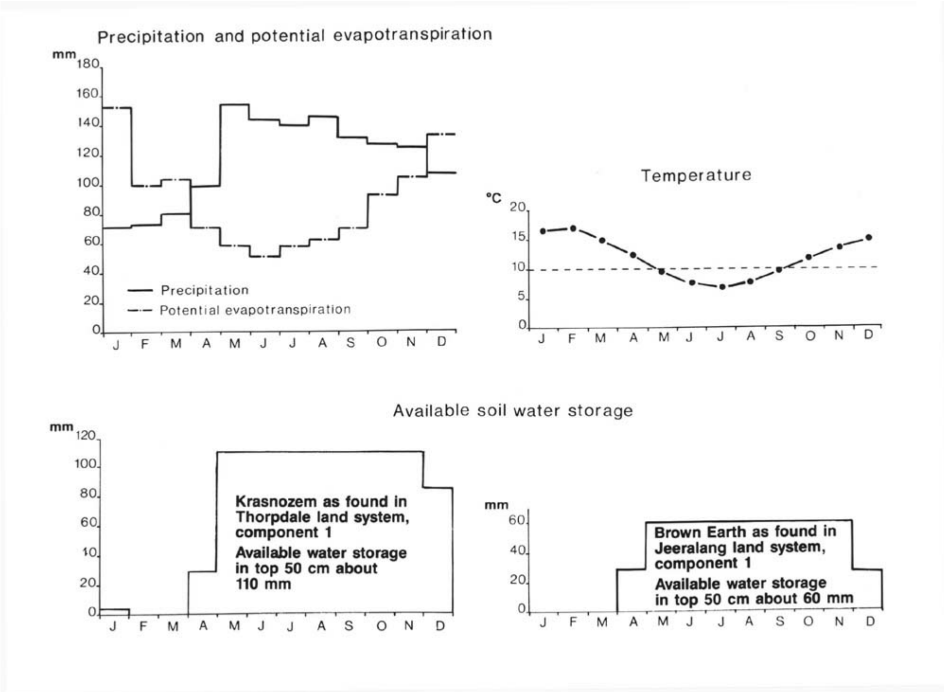


Figure 2.6 – The effect of available soil water storage on growing season.

Vegetation type

Species vary in rooting depth and hence in their ability to obtain moisture from the soil; they also have different tolerances to temperature and moisture stress. Many native species can take up water from the soil at levels well below the wilting point determined for agricultural species. The adequacy of the temperature and rainfall regimes of an area therefore varies according to plant species.

Estimate of growing season length

The period during which moisture and temperature regimes are suitable for plant growth can be crudely estimated by combining data on temperature, rainfall/potential evapotranspiration and available water storage capacity of the soil. Estimates of growing season for species which root to a depth of 50 cm are given for 8 localities in Figure 2.5.

In the higher country, the growing season is limited to spring and summer and to a short period in autumn before temperatures become too low. The growing season in the wetter parts of the lowlands, however, extends from early spring to early summer, with slow growth occurring over the cool period from June to August. In the drier parts of the lowlands, moisture availability probably limits growth in all months.

These estimates provide broad comparisons of length of growing season across the catchments but many factors limit their accuracy, for example, variable rooting depth of both native and introduced species, variable water storage capacity of soils, monthly averaging and the fact that loss of water by overland flow or subsurface flow is not taken into account.

Climatic and Water Supply

Annual water budget

An annual water budget for the Gippsland Lakes, based on their major catchments, is given in Table 2.7. About 75% of total precipitation is lost through evapotranspiration, some 20% reaches the Lakes, and about 5% is lost to ground water and to human consumption.

Input from precipitation and water loss by the different processes vary considerably from one catchment to another.

J. L. Thorpe (preliminary water budget for the Gippsland Lakes Catchment; unpublished report, 1977, Ministry for Conservation) estimated that evapotranspiration losses from downstream regions average about 170 mm per year less than for regions upstream, estimates being 565 mm and 736 mm respectively. The probable explanation is the higher rainfall and denser forests in the uplands, and the replacement of forests in the lowlands by pasture which transpire less.

Table 2.7 – Detailed annual budget by subsidiary catchment (thousands of megalitres)

Catchment	Precipitation	Evapotranspiration	Loss to ground cover	Net use	River flow to lakes	Percentage to total river flow to lakes
La Trobe R.	7, 755	3, 665	70	55	965	27.8
Thomson R.	1, 900	1, 335	59	54	452	13.0
Macalister R.	2, 114	1, 334	58	187	535	15.4
Avon R.	1, 540	1, 296	44	5	198	5.7
Mitchell R.	4, 384	3, 322	50	7	1, 005	29.0
Nicholson R.	496	417	23	0	56	1.6
Tambo R.	2, 272	2, 012	16	2	242	7.0
Lake Zone (land)	-	-	30	0	16	0.5
Total Lakes Catchment	17, 811	13, 685	350	307	3, 469	100.0
Lakes	246	389	-27	0	-	-
Total Lakes and Catchments	18, 057	14, 074	323	307	Flows to ocean 3, 353	-

Source: J. L. Thorpe (preliminary Water Budget for the Gippsland Lakes Catchment; unpublished paper, 1977, Ministry for Conservation)

Streamflow

Table 2.8 gives the estimated seasonal streamflows for the rivers flowing into the Lakes. About 72% streamflow occurs in winter and spring with the remainder evenly distributed throughout summer and autumn.

Rowe (1967) noted that soils above 1100 m in the Lake Hume catchment are never far below field capacity and contribute to streamflow by surface and subsurface flow at most times of the year following rainfall. Soils in the lower elevations with lower rainfall, however, often have moisture contents far below field capacity. Such soils when dry may produce run-off, particularly if the surface is hydrophobic. Once wetted, however, they contribute little to streamflow as infiltration occurs at the expense of run-off and there is no subsurface flow while the soil is below field capacity. Such soils at lower elevations with lower rainfall, however, often have moisture contents far below field capacity. Such soils when dry may produce run-off, particularly if the surface is hydrophobic. Once wetted, however, they contribute little to streamflow as infiltration occurs at the expense of run-off and there is no subsurface flow while the soil is below field capacity. A similar situation with respect to the relative contribution to river flow of soils at different elevations probably applies to the Gippsland Lakes catchments. Also, snow accumulation in the high country catchments. Also, snow yield by delaying run-off to streams until warmer months (Rowe 1967).

Table 2.8 – Seasonal streamflows (Thousands of megalitres)

Catchment	Winter	Spring	Summer	Autumn	Total
La Trobe R.	328	340	137	131	936
Thomson R.	143	148	53	58	402
Macalister R.	174	212	53	55	494
Avon R.	39	50	22	37	148
Mitchell R.	342	365	98	119	924
Nicholson R.	8	10	8	7	33
Tambo R.	62	66	46	41	215
Total	1, 096	1, 191	417	448	3, 152

Source: N. H. Howard (Gippsland Lakes Catchment water storage and hydrology; unpublished paper, 1976, Ministry for Conservation.

Climate and Erosion

Climate has a dominant effect on erosion rates, both directly through transport by water-flow and wind and indirectly through its influence on vegetation and soils.

Periods of high rainfall intensity are potentially critical for soil erosion by water, though the actual occurrence of erosion also depends on other factors, particularly the extent of ground cover which may be reduced by grazing, cultivation and other disturbances. Intense rainfalls are most likely from January to March, when vegetative growth is reduced in most areas due to water stress. This period, therefore, is a particularly critical time for water erosion.

The friable, light soils of the high plains and the loose sands along the coast are very susceptible to transport by wind when dry. As a result, the strong winds which occur in these areas can cause severe erosion if soils are exposed, particularly during the summer months. Frost action on bare soil further increases the susceptibility of alpine and sub-alpine soils to transport by causing crumbling.

3. GEOLOGY AND GEOMORPHOLOGY

J.M. Aldrick with a contribution by J. J. Jenkin

The Gippsland Lakes catchments can be broadly divided into the hill and mountains on consolidated rocks and the relatively flat terrain at low elevations formed predominantly on marine, aeolian, lacustrine and fluvial sediments. In this report, these two regions are referred to an 'uplands' and 'lowlands'.

The location of the uplands, which include both the East Victorian uplands and the South Victoria Uplands (after Jennings and Mabbutt 1977) and the lowlands are shown in Figure 3.1.

The first section in this chapter outlines the geology and geological development of the uplands and lowlands, and this provides a context for discussion of geomorphology in the subsequent sections. The final section considers the balance between current dominant landscape-forming processes, this being the basis for recognition of geomorphic provinces into which the land systems have been grouped (Chapter 7).

Much of this chapter relies upon the work of others, particularly on that of VanderBerg (1978, 1981), Jenkin (1968) and Bird (1961, 1963, 1965). Detail has been sought only to the extent necessary to allow the preparation of maps 1: 100,000 scale.

Geology

The Gippsland lakes drainage basin is geologically highly complex and this is reflected in the general topography, geomorphic patterns and soil distribution. Several aspects of geology, the history of earth movements (tectonics), their structural consequences, and the nature and formation of the earth materials themselves (petrology and stratigraphy), need to be considered (Figure 3.1).

The main features of geological history directly applicable to the present study, rather than a detailed overall description, are given below. Relevant detail will be found in figures 3.2 and 3.3 and in table 3.1.

Geological history

The oldest rocks exposed are Cambrian submarine basic volcanics, associated sediments and intrusives. Despite their small area, they represent a major event in the early structural history of east central Victoria and their outcrop trend are part of that tectonic style which dominated the Palaeozoic rocks until Permian times and is so strongly reflected in the differential erosion patterns of the Central uplands. The belt in which they occur, the Mount Wellington axis, lay between two depositional troughs which remained in existence until about the end of the Ordovician. In the Silurian they contracted markedly leaving most of the Gippsland Lakes basin, except in the far west, as land.

After more localised deposition in the Devonian and Early Carboniferous, with its associated volcanic and tectonic activity, the area became essentially one of subaerial denudation and appears to have remained relatively stable until the Early Cretaceous when there are signs of incipient marginal rifting and uplift of what are now the Eastern uplands. Intensification of this activity in the earlier part of the Tertiary appears to have been the principal factor in the elevation of the uplands initiating the dissection which fixed the positions of the major river valleys. The widespread basalts associated with this activity in the Eocene and Oligocene produced extensive volcanic plains and elongate valley flows, now represented by lava plateaux and residuals.

The lowland areas were initiated by down warping in the Paleocene and provided an extensive trough for highly complex sedimentary deposition ranging from terrestrial to open marine. However, by the Late Pliocene, the sea level had retreated to approximately its present level, the marine sediments being progressively overrun by alluvial fan and floodplain deposits.

Renewed earth movements in the Late Pliocene and Early Pleistocene (Koscuisko Episode, Table 3.1), have warped these sediments and are responsible for the broad outlines of the present physiography which may be resolved into a mosaic of blocks, differentially elevated, and bounded by faults or monoclines. It was in this context that the coastal sand barrier – lagoon and contiguous floodplain systems of the Quaternary developed.

Geomorphology of the Uplands

The tectonic framework outlined above provides a chronological overview of the major movements of geological material within the uplands and gives a crude picture of the major relief and how it developed. Modification of this land surface over time by weathering and erosion, has produced the present landscape.

Three aspects of the physiographic evolution of the modern upland land surface are considered here:
(i) the formation of erosion surfaces
(ii) differential erosion
(iii) Tertiary drainage modification

The formation of erosion surfaces

Beginning as long ago as the Permian and continuing through the Triassic and early Jurassic, a very long period of planation and deep weathering occurred. This resulted in an extensive surface of low relief know as the Gondwana Surface (King 1950). It was during the formation of this Mesozoic surface that the evolution of tropical rain forest progressed (O'Neil 1980) and the rifting of Australia from Antarctica began (Wilson 1976).

Since Australia became separated from Antarctica this ancient land surface has been elevated and eroded. The higher peaks along much of the Central Victorian Uplands are today roughly accordant and may represent the original Gondwana Surface. However, episodic uplift and periods of wet climatic conditions have led, over a long period of time, to stripping of the Mesozoic regolith and dissection of the underlying surface. Various authors (Hills 1975, Jenkin 1976, VandenBerg 1978, Neilson 1962) refer to this mildly dissected surface as the Baw Baw Surface, and cite the Baw Baw Plateau and the Snowy Plains as examples.

Three surfaces younger, than Baw Baw Surface have been recognized in the East Victorian Uplands by various authors (Table 3.2), but their ages and correlations are contentious; for example, VandenBerg (1978) considers that the Fumina Plateau (regarded by Hill (1975) as part of the Nillumbik Surface) formed during the same period of erosion as the Gregory Plateau.

The evidence from this survey supports the existence of at least two well established land surfaces younger than the Baw Baw Surface and older than the Kosciusko Uplift. There are no stratigraphic markers but, using the Older Volcanics as a guide, the presence of a pre-Older Volcanics surface can be inferred and in some places dissected remnants of this surface can be found, for example the Nunniong Tableland (Figure 3.4 (I)).

Remnants of a post-Older Volcanics landscape can also be found, for example in areas where relief inversion has occurred around the eroded remnants of the volcanics, which ere once valley fills. Here, classic 'valley-in-valley' forms have developed where the modern drainage has re-incised prior valleys. Other remnants exist on some north-south trending interfluves between the major drainage systems (Figure 3.4 (ii)).

Widespread and deep re-incision of drainage followed the Plio-Pleistocene uplift and produced vigorous erosion. As a result only small areas of the prior land surfaces remain and a 'ridge-and ravine' topography had developed over much of the rest of the area. Relief values of 500-700 m are common in the north.

Most of the South Victorian Uplands within the survey area consist of the northern slopes of the Balook Dome (Edwards 1942). This dome was elevated between two monoclines, mostly during the Pliocene-Pleistocene, but uplift may still be occurring (Hills 1975). Areas still relatively well preserved from major dissection occur along the spine of the dome near Grand Ridge Road and these areas have relatively low relief. Where dissection is deep and intense, the ridge tops are accordant and probably are part of the same erosion surface.

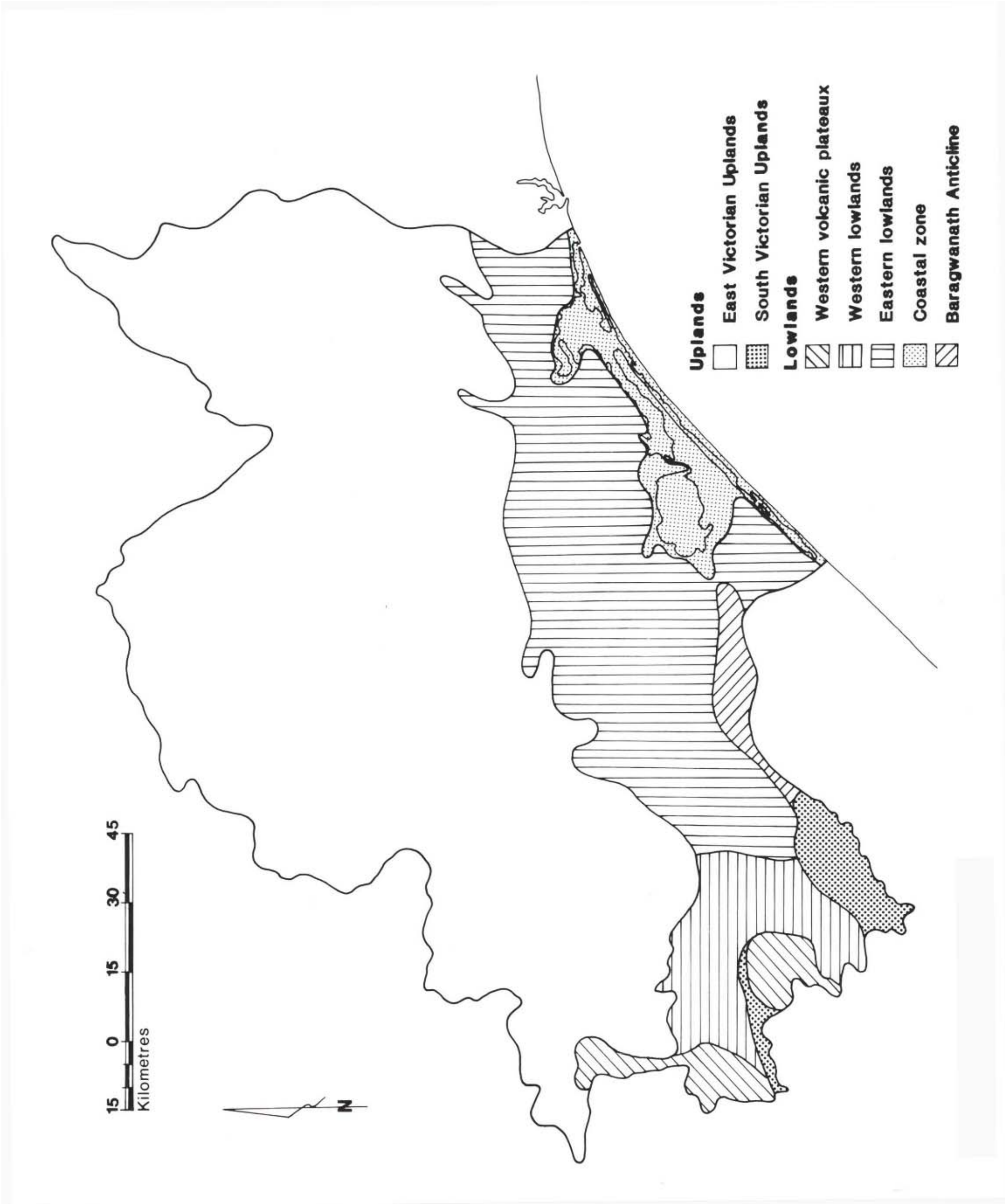


Figure 3.1 – Phyisographic units

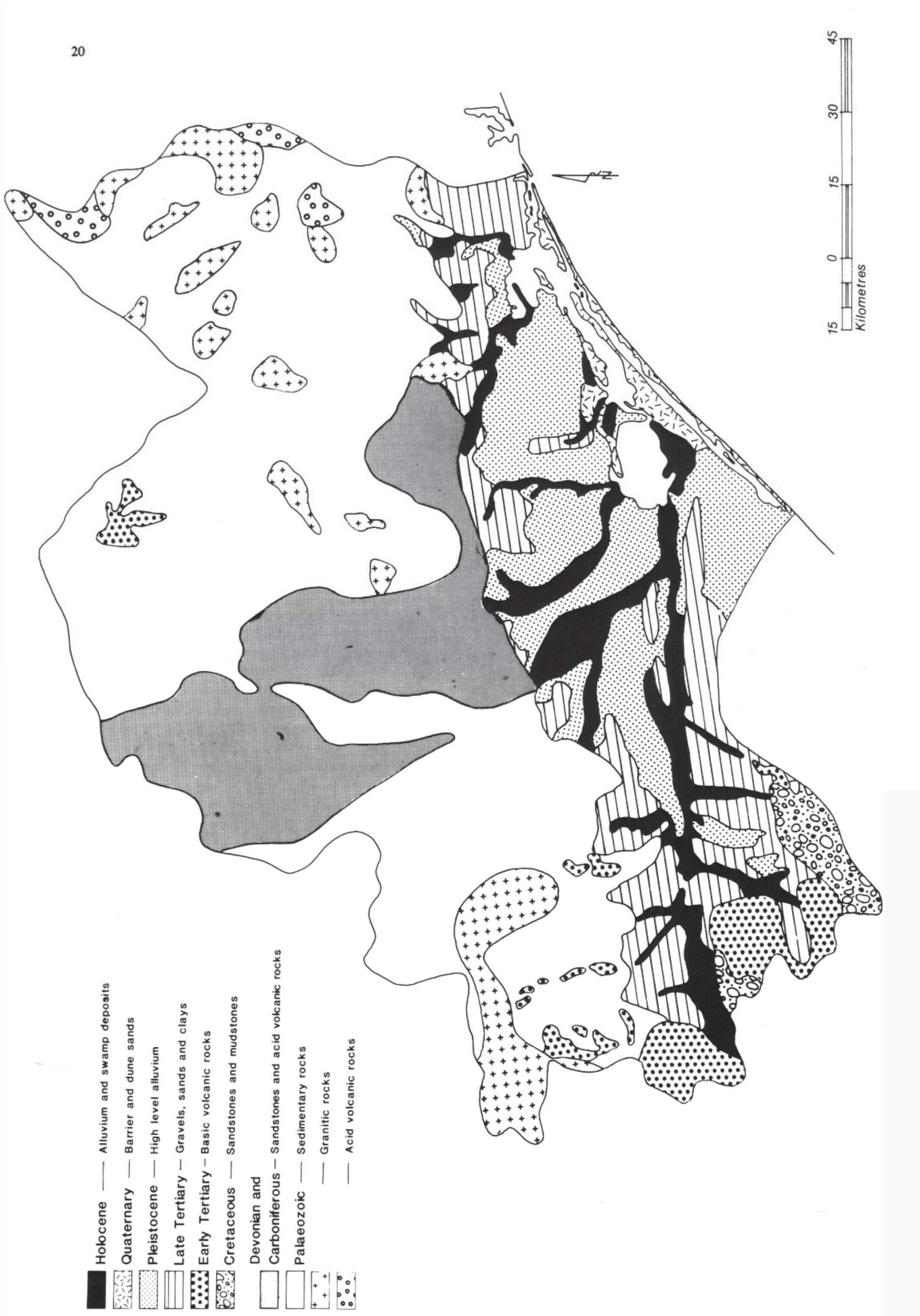


Figure 3.2 – Simplified geological map of the Gippsland Lakes Basin

Ages differences between the palaeo-surfaces have not been considered in the delineation of land systems as all the residuals have been eroded to some extent and many are difficult to allocate to a particular erosion cycle. Where prior land surface residuals occur, land system mapping had been based on topographic and ecological criteria rather than on age or genesis (Chapter 7).

Table 3.1 – Geology

AGE *Millions of years before the present (B.P.)			EVENTS	ROCKS
QUATERNARY	Holocene (Recent)	*		Floodplain deposits—sand, gravel, silt & clay Lagoonal silt, clay, peat; beaches, dunes & sand flats Swamps & bogs—silt, clay & peat
	Pleistocene	0.01 Fig. 3.3 (viii) Fig. 3.3 (ix)	Non-marine & coastal deposition; erosion	Alluvial terraces—sand, gravel, silt & clay Colluvium, alluvium, scree—silty & sandy gravel Dunes, beach barriers, lagoonal deposits Periglacial rock rivers—angular blocks High-level alluvial terraces—gravel, sand, silt & clay
	Pleistocene to Pliocene	Fig. 3.3 (vii) 1.8	Differential earth movement (Kosciusko episode)	High-level terraces—gravel, sand, silt & clay, often cemented by iron oxides.
TERTIARY	Pliocene to Miocene	24	Marine & non-marine deposition	Sale Group—gravel, sand & silt Seaspray Group—limestone, sandstone & marl
	Oligocene to Eocene	Fig. 3.3 (vi) Fig. 3.3 (v)	Non-marine deposition Earth movement & volcanism Non-marine deposition Erosion	La Trobe Valley Coal Measures—brown coal, clay & sand Olivine basalt; interbedded conglomerate, sandstone & shale Childers Formation—sand, clay, gravel & brown coal (Major unconformity)
CRETACEOUS	Early	145	Non-marine deposition	Strzelecki Group—Sandstone, mudstone, conglomerate
TRIASSIC		225	Intrusion Erosion	Granite porphyry (Major unconformity)
PERMIAN		280		
CARBONIFEROUS	Early	345 Fig. 3.3 (iv)	Non-marine deposition & volcanism	Avon River Group: Snowy Plains Formation- Siltstone, conglomerate Wellington Rhyolite—Rhyolite, some mudstone Conglomerate, sandstone & siltstone
DEVONIAN	Late		Intrusion Non-marine deposition & volcanism OROGENY	Granodiorite, granite, adamellite, aplite, & diorite Sandstone, siltstone, conglomerate, with intercalated basalt flows
	Middle		Intrusion	Granite, granodiorite, diorite & porphyry
	Early	Fig. 3.3 (ii) Fig. 3.3(iii) 395	Calcareous marine deposition Volcanism Marine deposition Intrusion OROGENY	Buchan Group: Taravale Formation—siltstone & limestone Buchan Caves Limestone—calcarenite, calcilutite, dolomite Siltstone, sandstone, claystone; some conglomerate & limestone Snowy River Volcanics—rhyodacite & rhyolite Sandstone, mudstone, shale, slate; includes Centennial Beds, Coopers Creek Formation & Tanjil Formation Granite, granodiorite, diorite
SILURIAN	Late		Metamorphism Volcanism Marine deposition	Biotite schist, phyllite, slate Rhyodacite, rhyolite; some andesite & tuff Sandstone & mudstone; some conglomerate & limestone
	Middle			
	Early	440	Intrusion OROGENY Metamorphism & intrusion	Granite, granodiorite, diorite Gneiss, schist & phyllite; granitic rocks
ORDOVICIAN	Late		Marine deposition	Sandstone, siltstone & shale
	Middle	Fig. 3.3 (i)		
	Early	500		
CAMBRIAN		570	Submarine volcanism	Greenstone, serpentine, diabase, tuff; chert & shale

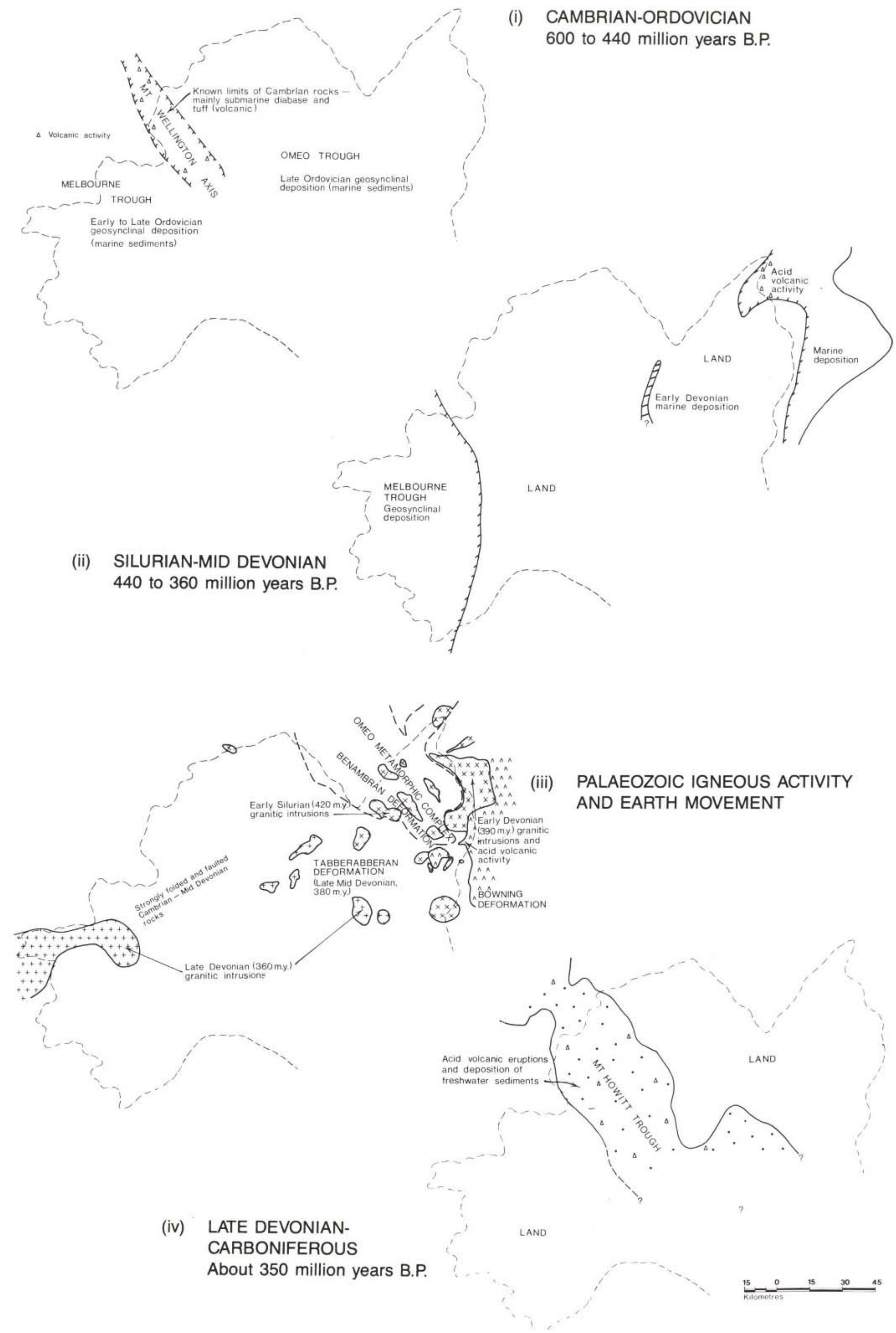


Figure 3.3 – Palaeogeographic maps

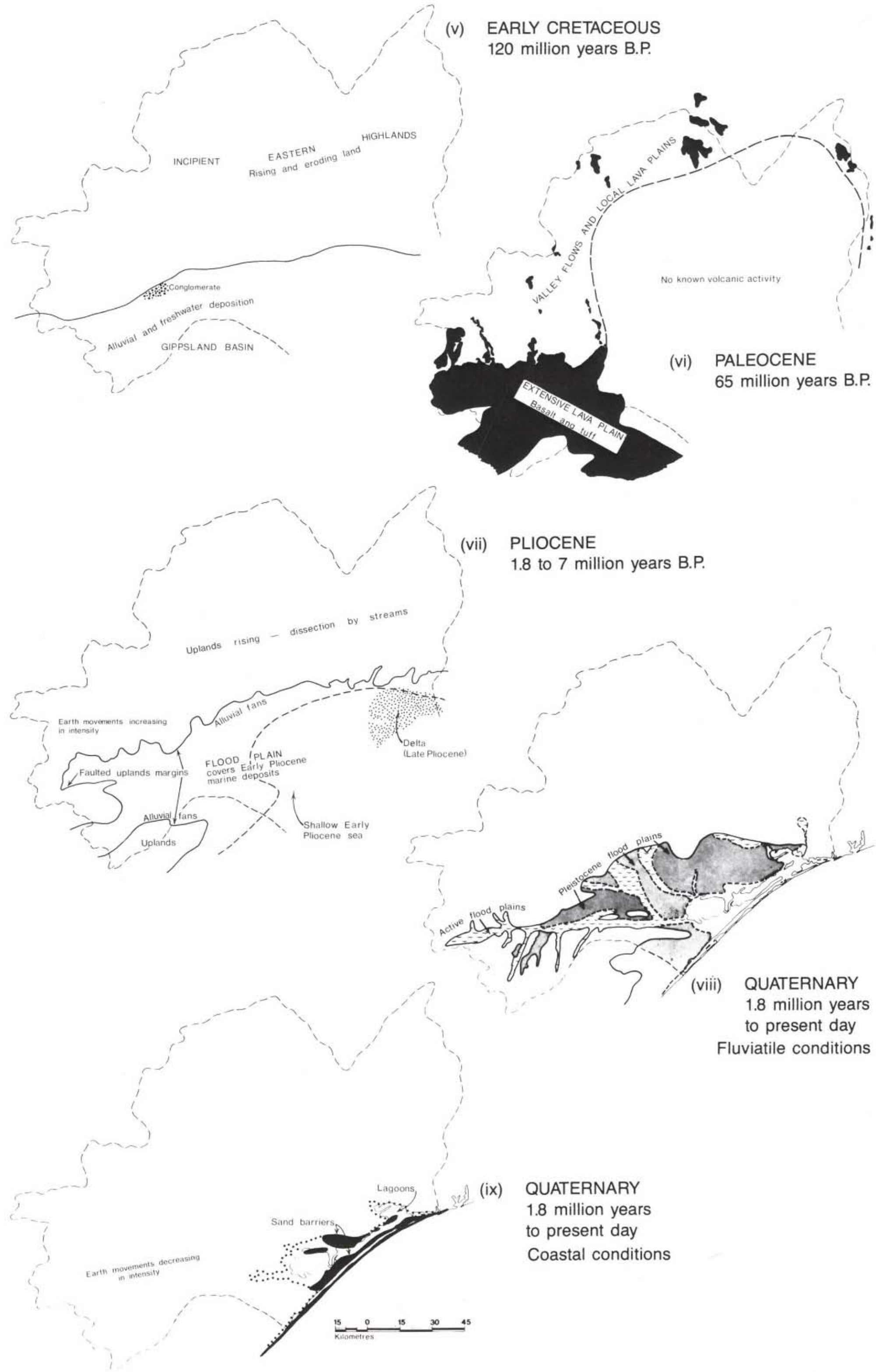

(v) EARLY CRETACEOUS
120 million years B.P.
INCIPIENT EASTERN HIGHLANDS
Rising and eroding land
Conglomerate
Alluvial and freshwater deposition
GIPPSLAND BASIN
VALLEY FLOWS AND LOCAL LAVA PLAINS
No known volcanic activity
EXTENSIVE LAVA PLAIN
Basalt and tuff
(vi) PALEOCENE
65 million years B.P.
(vii) PLIOCENE
1.8 to 7 million years B.P.
Uplands rising — dissection by streams
Earth movements increasing in intensity
Alluvial fans
Delta (Late Pliocene)
Faulted uplands margins
FLOOD PLAIN covers Early Pliocene marine deposits
Alluvial fans
Uplands
Shallow Early Pliocene sea
Pleistocene flood plains
Active flood plains
(viii) QUATERNARY
1.8 million years
to present day
Fluviatile conditions
Lagoons
Sand barriers
Earth movements decreasing in intensity
(ix) QUATERNARY
1.8 million years
to present day
Coastal conditions
15 0 15 30 45
Kilometres

Table 3.2 – Major older erosion surfaces in the survey area (after Jenkin 1976)

MID-TERTIARY	NILLUMBIK TERRAIN	Extensive erosion surface developed on Silurian and Lower Devonian sediments	Neerim South, Moondarra and further east
EARLY TERTIARY	PRE-OLDER VOLCANIC TERRAIN	Widespread – maturely dissected inland areas and flatter country to the south	Dargo High Plains, Aberfeldy and Tanjil area (beneath Older Volcanic lava flows)
CRETACEOUS	Including KINGLAKE SURFACE	Extensive plateaux	Kinglake and Gregory Plateaux
JURASSIC	MESOZOIC PENEPLAIN	Level summits on residuals of resistant rocks	Mt Baw Baw, Hotham Tablelands, Wellington Plateau, Bennison to Bryces Plains.
TRIASSIC	= BAW BAW SURFACE		
PERMIAN	Denudation glaciation		

Differential erosion

Stratigraphy and resistance to erosion have influenced the development of many of the major land forms. For example the sub-horizontally bedded resistant quartzose sandstones forming part of the Howitt Trough sediments now occur as plateaux at high elevation in the Mount Tamboritha, Mount Reynard and Mount Wellington areas, but softer 'redbeds' of the Howitt Trough and the bulk of the intensely folded and fractured Ordovician and Devonian sediments have eroded readily to a 'ridge-and-ravine' type of topography.

Within the survey area, gneisses and granitic rocks tend to be either erosion susceptible and hence tend to form either markedly 'positive' or markedly 'negative' relief; the different responses probably reflect differences in weathering history. The un-weathered Baw Baw Granodiorite, for example, has convex mountainous terrain at up to 1500 m elevation but the land surface on granodiorites and gneisses of the Swifts Creek-Ensay area is broadly concave, at elevation down to 250 m. Deep weathering of the material during a previous climatic phase and consequent ease of erosional removal may explain the latter case (Ollier 1965). Other examples of positive relief on granites included Mounts Nugong (Figure 3.5 (i)), Bindi and Baldhead. Other examples of negative relief are the Dargo (Figure 3.5 (ii)), Castleburn and Tambo Crossing areas.

Volcanic rocks, particularly the Wellington Rhyolites, the Snowy River Volcanics and the Older Volcanics, have also presented barriers to erosion. Many of the Older Volcanics flows were valley fills (Hills 1975) but, because of their resistance to erosion, the subsequent 30 or 40 million years have led to inversion of relief. The volcanics now cap high plains exposed around the margins and the coarser materials now function as seepage zones.

Tertiary drainage modifications

Ancestral drainage patterns were modified during the Tertiary by extrusion of the Older Volcanics, block faulting and stream capture (VandenBerg 1981).

Early Tertiary basalt flows filling river valleys caused some streams to abandon their former courses and incise twin-lateral systems. Thus the basalt flow near Aberfeldy caused the ancestral river to divide into the modern Thompson and Aberfeldy rivers. The La Trobe and Tanjil River systems were similarly affected (VandenBerg 1978).

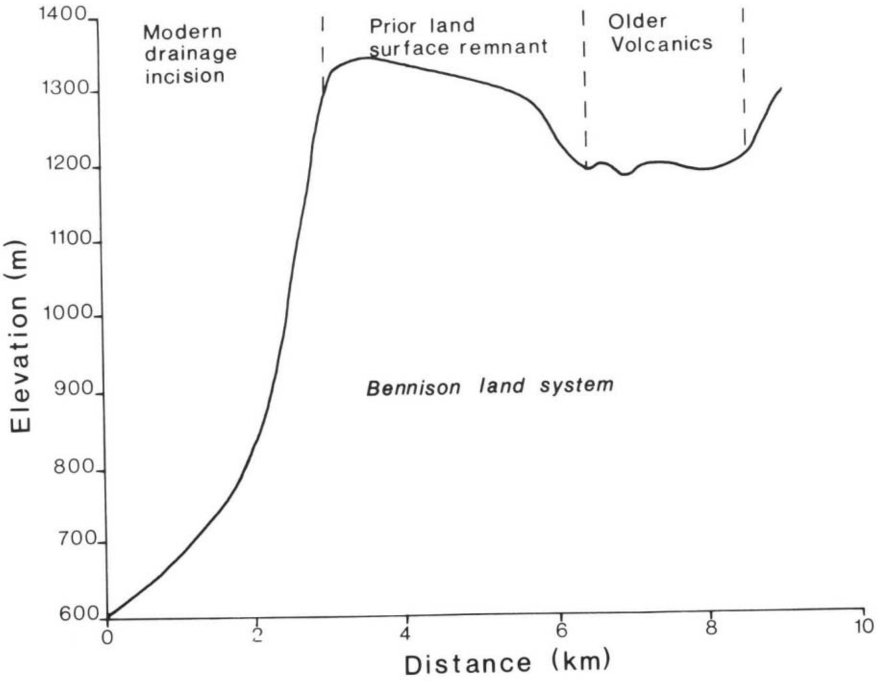


Figure 3.4 (i) – A prior land surface remnant east of Bindi, probably of pre-Older Volcanics age (Based on 1:100 000 topographic map).

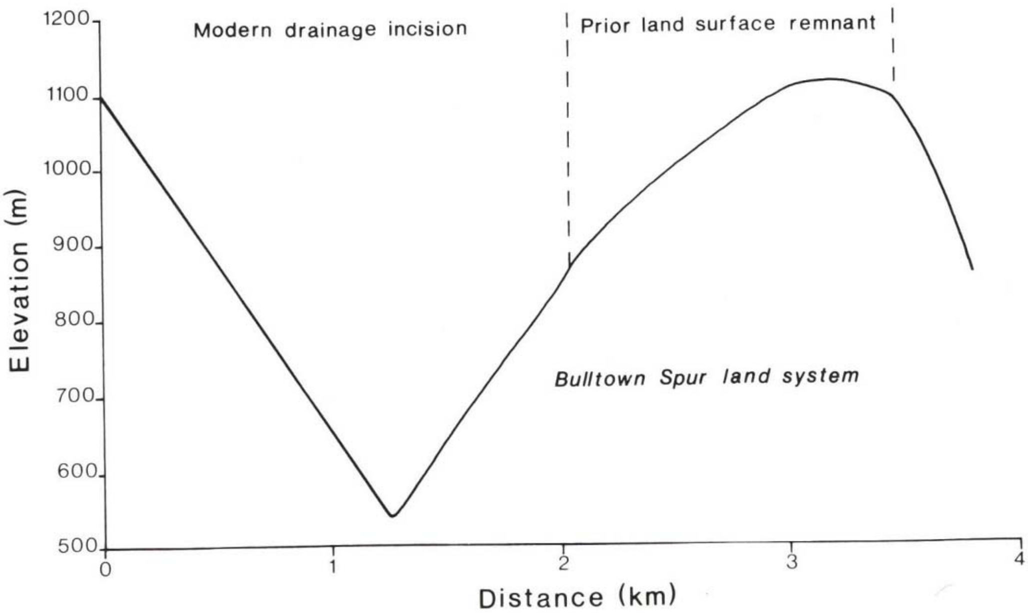


Figure 3.4 (ii) – A relatively steep prior land surface remnant north of Licola, probably of post-Older Volcanics age (Based on 1:100 000 topographic map).

In the mid Tertiary a major change in the drainage pattern occurred in the upper Tambo River system near Omeo. Some present tributaries of the Mitta Mitta River flow in a southerly direction towards the headwaters of the modern Tambo before turning northwards to join the Mitta Mitta. These tributaries may have originally formed part of Tongio Gap near Omeo (hills 1975). Mid Tertiary block faulting and tilting and a series of captures were probably responsible for the diversion and a consequent shift southwards of the main Divide (VandenBerg 1981). This history may explain the unusually low elevation of the Great Divide near Omeo.

Minor re-adjustments in the position of the Divide may subsequently have occurred. For example, it seems probable that the Baldhead branch of the modern Wentworth River was a tributary of the northward-flowing Livingstone Creek when the Divide was located as far south as Mount Baldhead. Subsequent capture by the Wentworth system has shifted the Divide northwards again as far as Mount Delusion (Figure 3.6).

In the mid tertiary the Buchan-Murrindal River system to the east of the survey area joined the lower Tambo-Timbarra River System and flowed out to sea near Nowa Nowa. However, in the late Tertiary the Buchan-Murrindal system was captures by a tributary of the Snowy River. The Tambo hand now lost major flow contributions from the Buchan-Murrindal system and its own previously captured headwaters north of Tongio Gap. The remainder of the Tambo-Timbarra flow was then captured by a small stream flowing south-west towards Bruthen, which became the modern Tambo River, and the original outlet near Nowa Nowa was completely defeated (VandenBerg 1981).

A similar diversion took place later in the Nicholson River system, which formerly flowed down the modern Clifton Creek valley further to the west (VandenBerg 1981). Thus much of the Tertiary alluvium along the lower Clifton Creek may originally have been deposited by ancestral Nicholson River.

The Geomorphology of the Lowlands

Five sub-regions (Figure 3.1) have been identified on the basis of their genesis, namely:

(i) the eastern lowlands
(ii) the coastal zone
(iii) the Baragwanath Anticline
(iv) the western volcanic plateaux
(v) the western lowlands

The landforms have developed from alluvial, marine, lacustrine, aeolian and volcanic materials, as well as minor colluvial and paludal deposits. Complex interactions of geomorphic processes have been involved and the following is a very much simplified account.

Reference is made to the land systems in this discussion because of the close connection between the relatively young geological and geomorphic history and the landforms and soils.

The eastern lowlands

A series of relict alluvial fans and terraces is a feature of this, the largest lowlands subregion. The fans are of Tertiary age and the three oldest terraces are Pleistocene, whilst the modern flood plains are Holocene (Figure 3.7). Sand sheets and dunes overlie parts of the two older races and some of the Tertiary materials.

The Tertiary deposits

The Late Pliocene was a period of renewed activity associated with the Kosciusko Uplift. During this time the alluvial fan and flood plain deposits of the Haunted Hills Gravels were laid down along the margins of the uplands. These deposits overlie the sand Boisdale Beds which constitute a major aquifer system.

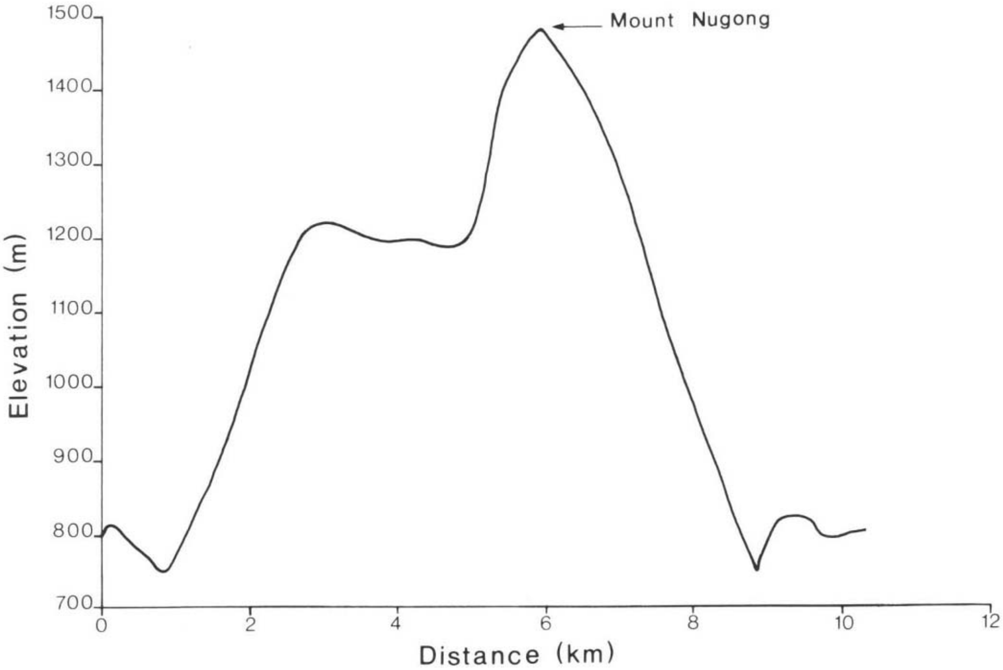


Figure 3.5 (i) – Positive relief of fresh plutonic rock (granodiorite) at Mount Nugong (Based on 1:100 000 topographic map).

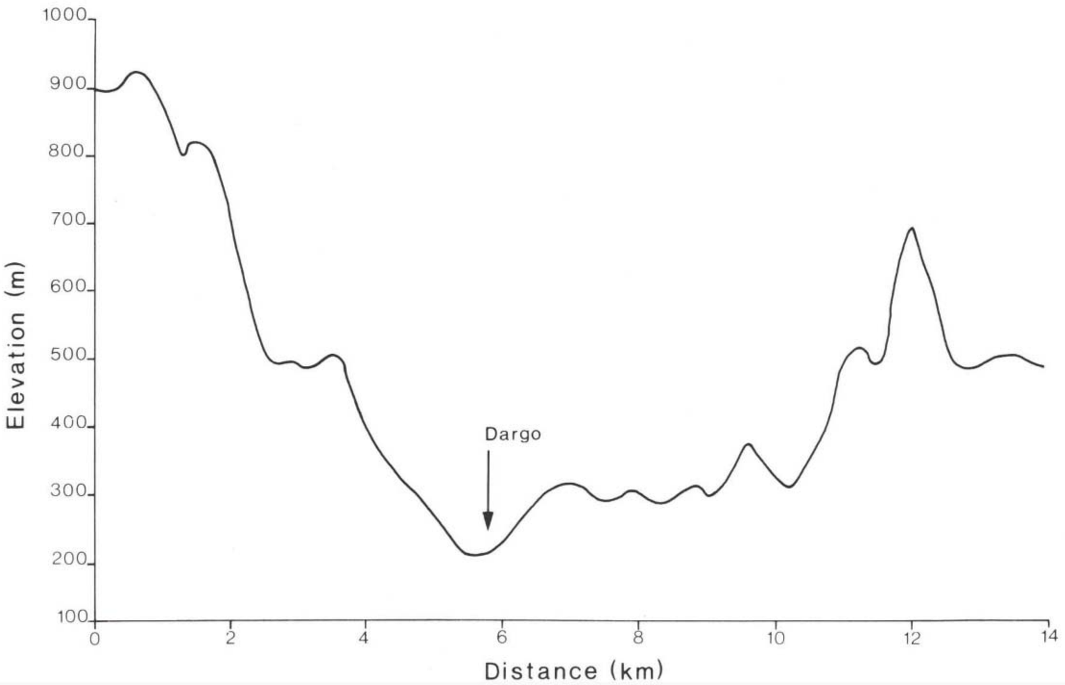


Figure 3.5 (ii) – Negative relief on pre-weathered plutonic rock (granite) at Dargo. (Based on 1:100 000 topographic map).

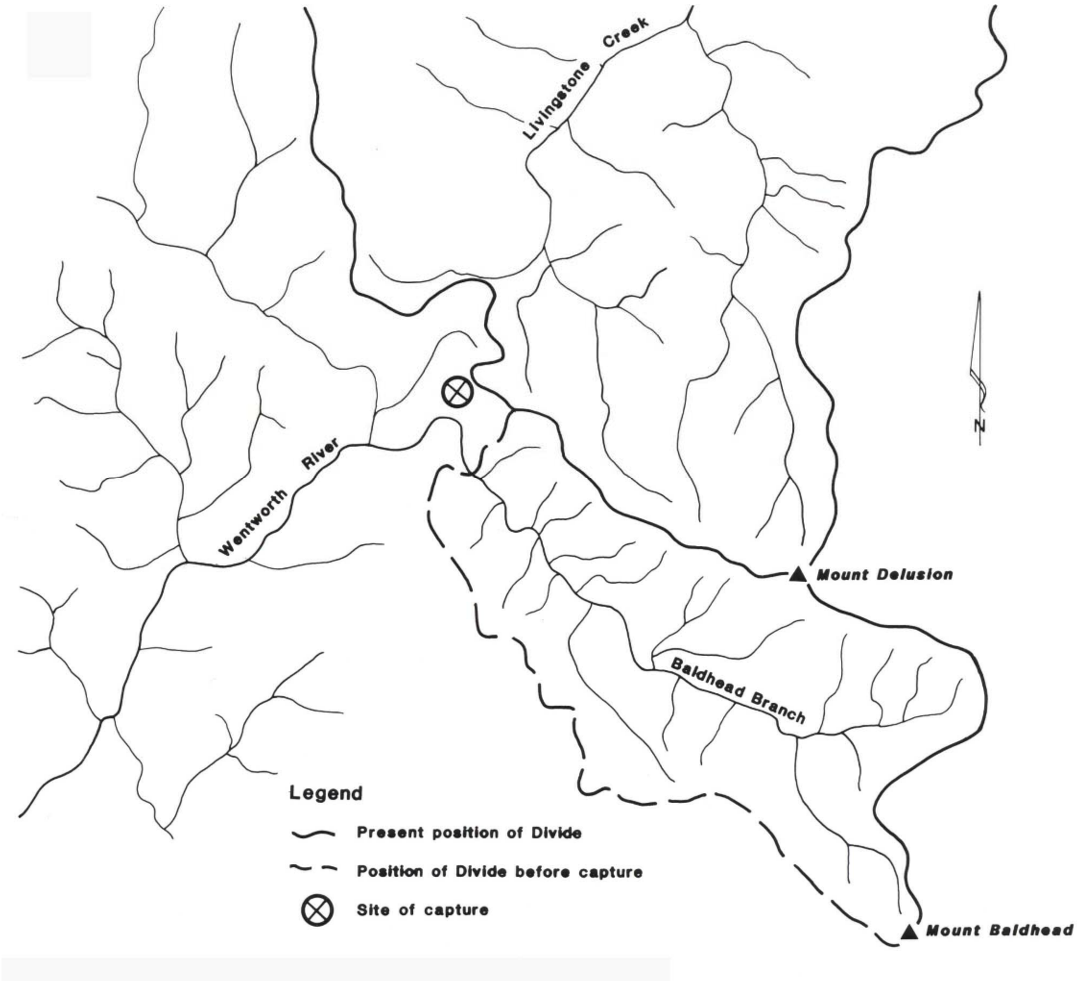


Figure 3.6 – Capture of the Baldhead branch by the Wentworth River

The Haunted Hills Gravels are characteristically variable, with particle sizes ranging from clay to boulders. Oxidation of the deposits is almost universal (Jenkin 1968) and a clayey plinthite strongly mottled with reds and greys often occurs at shallow depth, particularly where the original land surface is preserved. Ironstone remnants have been noted immediately to the south of Lake Glenmaggie, where they mined for road gravel. The sandier deposits have contributed large quantities of sand to some drainage corridors and thence to the littoral area.

Erosion of the Tertiary land surface is now well established and few area of the original surface remain. Many factors have influenced the dissection. Tectonic warping, including a series of monoclinical movements, had raised some of the deposits well above modern stream level (Jenkin 1968) providing the potential for extensive downcutting. Dissecting is particularly well advanced close to the uplands, due partly to uplift and also to the coarser nature of the deposits and their slope.

The land systems of the Tertiary fan and flood plain deposits of the eastern lowlands have been delineated on the basis of topography and climate and associated differences in vegetation. The almost flat plains are in Redgum 1 land system whilst the more gently undulating and dissected areas are in Westbury I land system. Deeply dissected areas, usually on the relict fans, are in Salt Creek land system if drier and with Redgums (*E. tereticornis*) r in Anderson 1 if without redgums. Areas with remnants of the original surface are in Clifton land system and the sandier deposits are mapped in Stockdale land system.

Tertiary fan deposits also found within the western lowlands

The earlier Pleistocene terrace

Towards the end of the deposition of the Haunted Hills Formation, a marine regression caused deep valleys to be cut in the Tertiary plains to levels below those of the present flood plain. This was followed by an apparent rise in sea level to 33.5-36.5 m above present levels and the alluviation of the previously cut valleys (Jenkin 1968). During this time the deposits mapped in Redgum 2, Dutson and part of Redgum 1 land systems were laid down. A subsequent slight sea level led to the formation of a slightly lower flood plain, on which Valencia land system has been mapped. Another major marine regression followed, and these flood plains were left as two terrace levels flanking the Tertiary deposits (Jenkin 1968).

Recent work by Jenkin (1981) has suggested that differential earth movements combined with absolute sea level changes have resulted in stranding and elevation of old coastal forms.

Permeable sand sheets have protected some deposits from dissection by precluding local run-off. In the prevailing climate, a 30-60 cm depth of sand can offer effective run-off protection. However, after run-off induced erosion of adjacent clays, dune-like residual forms may remain, with clay layers beneath a shallow overlay of permeable sand. This type of dissection has caused most of the sands to occupy the higher positions.

South of the Mitchell River floods plain in the terrace deposits are relatively shallow, overlying Miocene limestones of the Seaspray Group (the Gippsland Limestones). In this area, which is a component of Redgum 1 land system, sinkholes have affected the dissection pattern.

Drainage incision often follows deep gravel deposits. The impermeable pebbles and stones may constitute over 90% of the materials, and , in these areas, rainwater rapidly saturates the earth matrix, rendering it unstable.

These Pleistocene terraces, together with the more distal flood-plain deposits of Tertiary age constitute the ‘redgum plains’ of Gippsland. The original almost flat surfaces are widely preserved and here land systems often contain almost only one component.

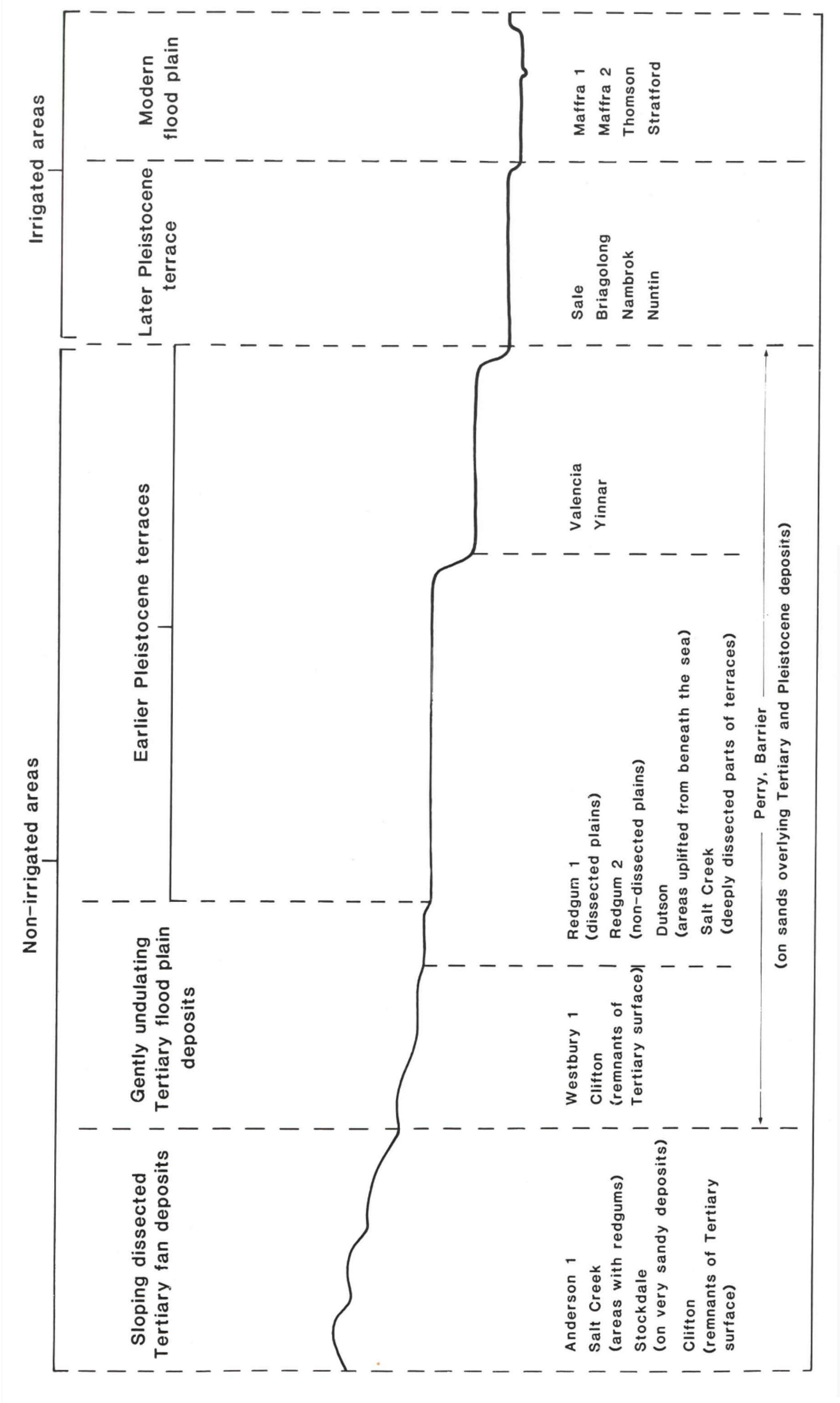


Figure 3.7 – Diagramatic cross-section of the eastern lowlands sub-region. Typical land systems are shown

The inland sand sheets and dunes

Extensive sand sheets and dunes occur on parts of the Tertiary and earlier Pleistocene land surfaces, especially to the north and south-west of Lake Wellington. These are mapped in Perry and Barrier land systems.

The presence of former sea-cliffs, barriers, foredunes, bars and tidal forms has been reported in these areas by Bird (1961, 1963, 1965), Jenkin (1968) and Ward (1977) and Ward has proposed that the sand sheets and dunes have a marine origin. Their presence at elevation up to 128 m a marine origin. Their presence at elevations up to 128 m above sea level, far higher than the level the sea would reach if all t he world's ice were to melt, was attributed by Ward (1977) to continuous uplift of the land in addition to glacio-eustatic sea level rises. Jenkin (1968), Ward (1977) and Bird (1961, 1963, 1965) recognised aeolian forma amongst the sand deposits and these they ascribed to both initial foredune construction and subsequent aeolian alteration of marine deposits.

In the Seaspray-Dutson area some of the dunes of Barrier land system are linear with relatively steep forests and are oriented roughly parallel with the coastline. These are believed to be stranded foredunes. The sand sheets of Perry land system in this area include irregular low ridges, hummocky sand deposits aligned with the coast and more or less linear poorly-drained swales. These features could possibly be old sea-floor forms. The clay flats of Dutson land system here have relatively saline solonetzic soils, which also argues for a marine history.

The sand sheets and dunes in the Stratford-Bairnsdale area have many similarities with those of the Seaspray-Dutson area but no unequivocally marine forms could be found there during this survey. No stranded beach-lines or old marine terraces were found, although Ward (1977) has reported their presence in the area. The soils of the adjacent plains between Stratford and Bairnsdale are usually Yellow Podzolics or Solodic Soils with no evidence of high salinity in their pedogenetic history.

A possible origin of these dunes ands sand sheets is redistribution of sands fro the Perry Merriman Creek systems. These streams drain dissected sandy Tertiary deposits near Stockdale and along the Baragwanath Anticline. Abundant sand deposits characterize the channels of these stream today. Lesser quantities of sand also appear to have been derived from the flood plains of Blakall Creek and the Avon River below Stratford. These streams also drain the Stockdale area but much of their sand load seems to have reached Lake Wellington.

Distribution of the sand from the stream courses to its present position could have occurred in response to beach and longshore drift mainly towards the east, but possibly at times towards the east, but possibly at times towards the west, and this would be consistent with Wards (1977) theory. However, VandenBerg (1977) theory. However, VandenBerg (1981) regards most of the dunes in the Stratford-Bairnsdale area as being younger than the terraces upon which they lie and this argues against Ward's (1977) coastal terrace theory.

A more likely mechanism is direct aeolian distribution, similar to that proposed for parts of the Riverine Plain in New South Wales by Mabbutt (1980). Much of the sand may have been blown from the alluvial deposits during times of low sea level and cold dry climatic conditions. The largest dunes, at least in the Perry catchment, lie immediately to the east, i.e. downwind, along the whole length of the Perry flood plain (Figure 3.8). The down-wind linearity of form is maintained even where the sands lie on a succession of Pleistocene terraces (Qp2, Qp4 and Qp5 of VandenBerg 1981) and on Tertiary deposits at various levels.

Jenkin (1981), however, regards the raised forms as old levees, deposited in a Late Pleistocene delta complex but now with aeolian sand cappings, probably blown from the river systems as described above.

In its passage across the plains some of the aeolian sand was intercepted by Tom Creek and similar sand cappings were derived from the Tom Creek flood plain. Sand which remained in Tom Creek had reached Lake Victoria at Jones Bay.

The sand deposits have been subjected to rainfall erosion but are relatively stable under the influence of the present climate.

The later Pleistocene terrace

When sea level fell after deposition of the earlier Pleistocene terraces, it receded to substantially below present sea level. The rives became entrenched in their valleys and substantial excavation of alluvium occurred (Jenkin 1968). At this time the Tertiary deposits, the two earlier Pleistocene terraces and the overlying sand sheets and dunes became relict and were no longer subjected to depositional influence.

However, another marine advance followed, this time to 12-15 m above present sea level and extensive alluviation occurred within the recently cut valleys. During this time the materials of Sale, Briagolong, Nambrok and Nuntin land systems were deposited. Towards the close of this phase sea level slowly fell, leaving the third well-developed alluvial terrace and coastal lagoons that were to become the Gippsland Lakes. This sea level fall was mapped in Freestone land system, can be identified along parts of the lower margin of the third terrace.

Most areas of the later Pleistocene terrace occur south of the Thompson River between Cowwarr and Sale but small areas occur elsewhere, for example immediately south-east of Bairnsdale.

The presence of duplex soils in well-drained areas of Sale land system are indicative of an altered pedogenetic regime from the initial flood-plain conditions to one of rainfall leaching (Chapter 4) and this is consistent with the geomorphic evidence.

The courses of prior streams on this terrace are clearly marked by a series of relict alluvial ridges, which are slightly raised above the level of the clayey plains. These have been mapped in Briagolong land system having characteristically reddish soils.

Generally the prior streams are relatively small compares with the extent of the terrace and may not represent the main course of the ancestral Thomson, Macalister or Avon Rivers. Just north of Sale, however, an area of Briagolong land system with somewhat larger palaeochannels and levees occurs and it is likely that a significant stream, possibly part of the Thomson or Macalister systems, once flowed eastwards through this area. Also, areas of reddish alluvium (Briagolong land system) occur intermittently at the edges of the later Pleistocene terrace beside the modern Thomson flood plain and may represent remnants of formerly extensive river levees. Allowing for considerable erosional removal of materials from the edge of the third terrace during formation of the lower modern flood plain, it is possible that the ancestral Thomson occupied a course very similar to its present one.

Near Briagolong and between Cowwarr and Denison extensive areas of reddish alluvium (Briagolong land system) occur close to the points of emergence of the ancestral Avon and Thomson Rivers from the hills and probably represent proximal sections of discharge fans, coarser and more steeply sloping than the bulk of the alluvial plain. (Similar forms occur on the Upper Mitchell and Macalister flood plains but they are modern and are contained within Maffra I land system.).

Low aeolian mounds have been built on the later Pleistocene terrace where the terrace edge was exposed downwind of the river valleys during the last glaciation. Examples occur east of the Thomson-Macalister River junction between Sale and Maffra. Because of their general similarity to the sandier levees, most of these have also been included in Briagolong land system.

Nuntin land system mapped on what are probably eroded and truncated remnants of alluvial ridges formed along straighter reached of the prior streams in further downstream positions (Jenkin 1968). Some aeolian alteration had since occurred. Most occurrences are between Sale and Lake Wellington, and immediately south-west of Sale.

Poorly-drained areas of the third alluvial terrace occur in low-lying areas, probably old back-swamps, and along the northern edge of the Snake Ridge Monocline where the uplifted block of Tertiary deposits has formed a barrier to drainage. These areas of poor drainage are mapped as Nambrok land system.

Since irrigation of this terrace began, groundwater levels have risen to the surface in areas of Nambrok land system and artificial drainage has been necessary (Webster and Webster 1965).

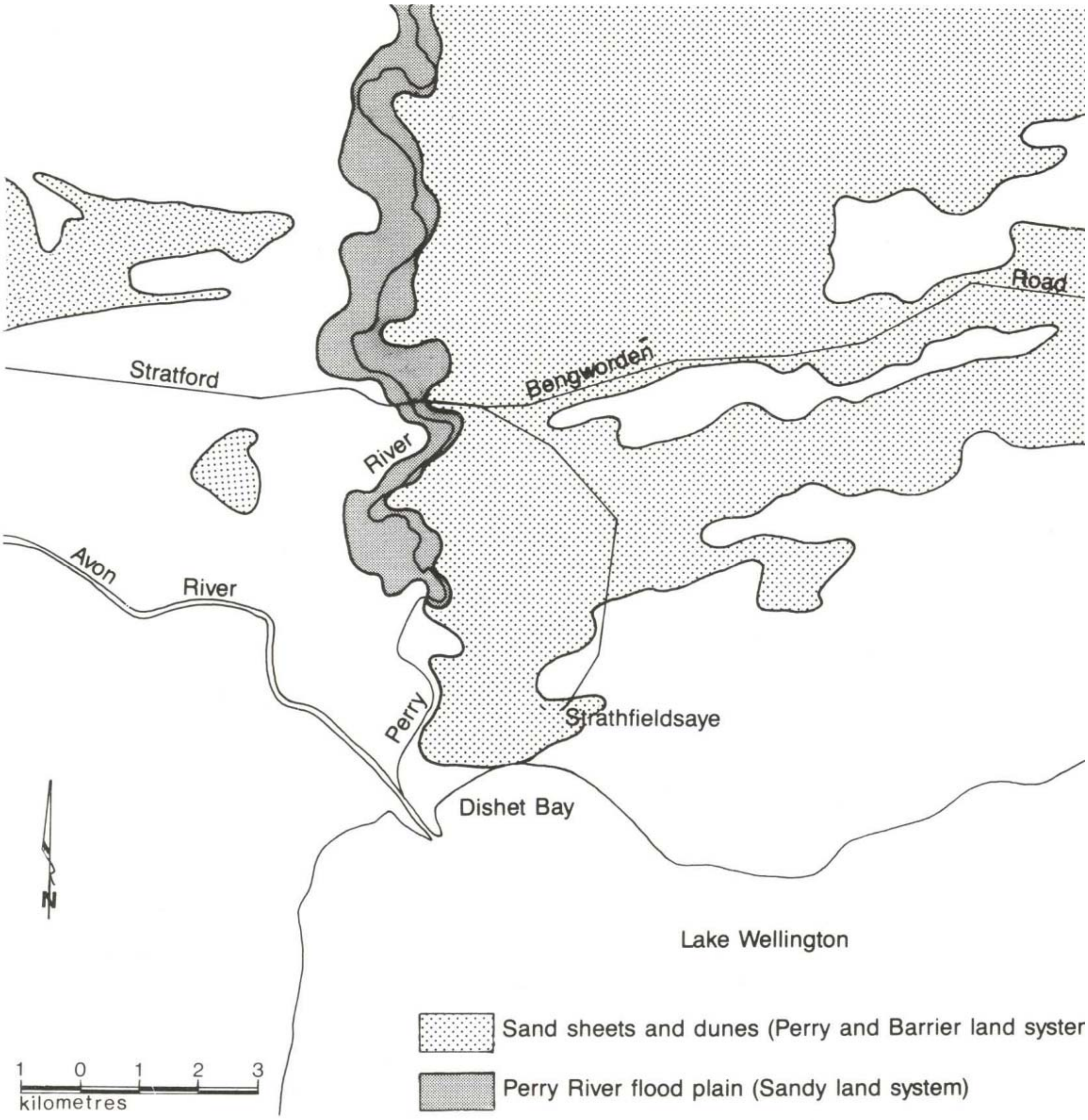


Figure 3.8 – Sand sheets and dunes extend mainly eastwards from the Perry River floodplain to the north of Lake Wellington

The modern flood plains

As discussed in the previous section, sea level fell after formation of the later Pleistocene terrace. This fall was to at least 24.5 m and possibly more than 110 m below present levels (Jenkin 1968) and at this time a land bridge to Tasmania may have been existence (Jenkin 1968, Mulvaney 1975). Again, the river systems incised deep valleys in their earlier alluvial deposits and the existing coastal lagoons, precursors of the Gippsland Lakes, were drained.

The Holocene marine transgression that followed refilled the valleys and led to the formation of the flood plains. Slight stream incision and lateral corrosion were observed on the modern flood plains during this survey, suggesting a subsequent slight fall in sea level. The implications are discussed at the end of this section, although the causes for the transgression and subsequent fall in level are not certain. Bird (1961, 1963, 1965) and Jenkin (1981) acknowledged that a slightly higher Holocene sea level might have occurred but suggest that widespread epeirogenic uplift accompanied by more local transverse tilting is more likely to have been the case.

Much of the modern flood plain has high quality agricultural soils ideally suited to irrigated use (Chapter 4). Important aquifers underlie these soils (Nahm 1977). On the flood plains where low discharge fans have formed adjacent to the hills, relatively large areas of reddish 'levee' deposits occur.

The shape of the modern flood plains had been influenced by the location of resistant rock barriers. Jenkin (1968) cites ferruginous conglomerate as being responsible for construction of the Thomson River flood plain near Sale and the Bairnsdale Limestone as influencing the development of the lower parts of the Tambo, Nicholson and Mitchell River flood plains. VandenBerg (1981) points out that the easterly trend of the Mitchell flood plain follows the junction of coarse unconsolidated Tertiary deposits and the more resistant Bairnsdale Limestone.

Four geomorphic situations exist on the modern flood plain, as outlined below:

(i) Remnant of the original depositional plains, so far unaffected by more recent stream entrenchment. These area, mapped as Maffra 2 land system, are almost flat with very few levee, channels, or other fluviate forms. Flooding occurs only during very high floods.

(ii) Slightly lower land, more frequently flooded and characterised by abundant small sinuous channels, oxbows, crevasse splays, some small levees and discharge fans. The levees represent temporary local storage of material in a longer-term erosional regime. This land is mapped in Maffra 1 land system.

(iii) Even lower areas, mapped as Thomson land system, containing the major meandering river systems, abundant oxbows and other fluviatile land forms, and relatively frequently flooded. Small levees occur along parts of the river banks but as in case (ii) above, they represent relatively short term sediment storage only and alternate with stream-bank erosion. Stratford land system also occupies this position but it is a special case and is discussed separately in a following section on river bank erosion.

(iv) The flood plains furthest downstream are actively depositional. Prominent levees flank much straighter reaches of the rivers, and deltas, distributary channels, and in-filling swamps are common. These depositional flood plains are mapped as Delta land system

The first three situations represent successive stages of stream incision. The external influence could be epeirogenic uplift as favoured by Bird (1961, 1963, 1965), or a recent sea level fall. The fact that the four major post Tertiary terrace levels exist at successively lower elevation is more likely to indicate continuing Quaternary uplift than a generally falling sea level, particularly as sea levels are now high. The same argument may apply to the minor variation in levels within the Holocene flood plains.

The flood plains are in an erosional phase with an overall erosional removal of material towards the Gippsland Lakes by swinging meander planation and stream bank erosion. Disturbance of frontage vegetation or of the stream banks themselves may exacerbate this situation unless geomorphic principles are considered.

River Bank Erosion

Braided channels typically with large, coarse bedloads and anastomising flow paths have developed along most of the lowlands tract of the Avon River and Freestone Creek, along parts of the Mitchell and Tambo rivers, and in Rainbow Creek. They are mapped as Stratford land system and appear to be the only occurrences in East Gippsland. The braided condition, at least in the Avon, has developed since European settlement (Jenkin 1968) and, as considerable streambank erosion and loss of quality farm land is occurring, separate discussion is warranted.

Such a change in geometry could be cause by a variety of factors. Jenkin (1968) discounts climatic or base-level change, as not all streams are affected, and modification of upper catchment areas, as more than one stream is affected. He regards human interference as the most likely factor and this is supported by the time of onset of the change in the Avon River. Jenkin concluded that removal of protective plant cover along river banks has been the cause and that the result is most pronounced in the Avon River because the material through which it flows is coarse and easily eroded compared with the finer, more compacted materials along other streams.

In the region where the La Trobe, Thomson, Macalister and Avon Rivers traverse the lowlands, changes in base level and tilting of the land surface would have occurred frequently. Field observations indicate that there may be a tendency, strongest I the north, for the courses of these rivers to be currently moving southwards. It would seem that the Macalister River has already vacated an original channel to the north of its flood plain (Newry Creek), now flowing down a more central line, and that its tendency now is to move further south into Boggy Creek. The Thomson river has largely avulsed southwards into Rainbow Creek, and midway between Rosedale and Traralgon there is some scouring along a more southerly course of the La Trobe River. In the case of Rainbow Creek, mechanical straightening and enlarging of the bed have facilitated the change.

A tectonic factor may be involved in the formation of the braided condition of the Avon River. The Avon River flows more or less southwards and, if a southerly downwards tilt occurred, the immediate result would be increased channel length (Schumm 1977). However, if the rate of tilting exceeded the capacity of the stream to respond, a threshold would be passed beyond which the river would rapidly change to a bedload stream with a braiding channel pattern (Garner 1974). It seems likely that the effects of European settlement (as outlined by Jenkin 1968) have precipitated the Avon River across such a threshold and allowed the braided condition to develop.

An additional possibility in the case of the Avon River is that bank erosion is caused by a rise in water tables due to irrigation. In coarse materials, such as occur under the Avon River and Freestone Creek flood plains, the normal water table near the river would be at river level. As a know aquifer, the Boisdale Beds, outcrops in these streams (Jenkin 1968), an externally-induced water table rise would be readily transmitted to the river channel area, effecting a local base-level rise. The gradient of the river bed would then be effectively lowered and, in a compensatory response, the river would alter towards a channel of reduced length such as a less-sinuous or a braided channel pattern (Schumm 19770. A raised water table would therefore, tend to compensate for an increased grade sue to tilting.

For braided configuration to be sustained a large bedload is required and, if the river could not corrode its bed, it would acquire bedload materials but corrosion of its banks. This is consistent with the situation in the Avon River, where there is little evidence of incision but abundant evidence of lateral plantation and siltation.

Most of the irrigation water applied along the right bank of the Avon River is diverted from the catchment of the Macalister River via Lake Glenmaggie and amounts to about 430 mm of additional water per annum in a 600 mm rainfall zone, an increase of over 70%. Water tables have not been monitored but groundwater has appeared in some of the drains and a few flowing bores now occur (R. Kermode, personal communication). This apparent rise in groundwater levels has not let to major irrigation problems although it may be contributing to the bank erosion problem. However, most of the bank erosion on the Avon River occurs at times of high flood flow when water tables effects are relatively insignificant so that a raised water table must be regarded as an exacerbation of the problem rather than a cause.

If the bank erosion along the Avon River is due to tectonic tilting or raised water tables, lasting control is not likely to be achieved by placement or bank protecting structures that inhibit lateral planation. In the case of tilting, channel configuration must ultimately become more sinuous for stability and, in the case of raised water tables, siltation of the present channel and ultimately avulsion to a more steeply sloping area are likely to occur. If control is require without further significant change in channel geometry, flood mitigation structures would provide the most certain result. In contrast, if bank erosion is due to disturbance of frontage vegetation, local control structures would probably be effective.

The Coastal Zone

The present coastal morphology has taken shape since the Late Pleistocene. It is a complex and dynamic zone situated at the interface of processes of the land, sea and atmosphere, and with local geology influencing the interaction of these processes.

A marginal bluff, once a former sea cliff, separates the coastal zone from the eastern lowlands and meets the seat east of Lakes Entrance. The cliff is inherently unstable and erosion had been increased by human activities.

The barriers

Three barriers were recognised by Bird (1961, 1963, 1965). A 'prior' barrier stands to the north of the Lakes beneath the former sea cliff, an 'inner' barrier occurs north of Lake Reeve and an 'outer' barrier lies to seaward and carries the Ninety Mile Beach. Each barrier is surmounted by beach ridges and dunes.

According to bird the prior barrier was formed at a time of slightly higher sea level in the Pleistocene. It has since suffered considerable dissection and re shaping by fluvial, aeolian, paludal and lacustine processes. The inner barrier originated as a recurved spit south of Lake Wellington, was prolonged north eastwards across the mouth of the embayment, and widened by the addition of a series of beach ridges. Dissection and re working of parts of the inner barrier has also occurred, probably during Late Pleistocene times. Bird notes that the materials and forms of the prior and inner barriers are similar, and considers that there is very little age difference between them.

The extension and entrenchment of the river systems that occurred when the coastal lagoons were drained during the Late Pleistocene sea level fall was responsible for a large part of the dissection of these two barriers and the accompanying climatic conditions caused much of the aeolian modification (Bird 1961, 1963, 1965). Lacustrine and paludal modifications occurred during the last sea level rise, particularly east of Sperm Whale Head where subsidence of much of the inner barrier appears to have occurred. Also in this area, a tract of dunes was formed in Holocene times to produce the southern portion of the Boole Poole Peninsula (Bird op cit).

The land systems mapped on the barriers are based on genesis as well as form and consequently they express a pattern that correlates closely with the geomorphic findings of Bird.

The prior and inner barriers, both the intact beach ridges and the sections which have undergone lacustrine reworking, are mapped in Seacombe land system. Clown out areas with parabolic dunes derived from the inner barrier deposits and with dry sandy floors are mapped in Banksia land system. Where aeolian excavation has reached a water table which has prevented further removal of sand, the parabolic dune formations that remain have swampy floors which are mapped as the Morass land system.

Tyers land system occurs where subsidence of the inner barrier occurred and a more humid climate prevails. This landscape contains the tops of the sand ridges which were left above lake level after subsidence and the now intervening flats of lacustrine and paludal dill. The Holocene parts of the inner barrier in this sand area are in Rotamah land system.

The outer barrier was formed by landward movement of sea floor sand deposits during the Holocene marine transgression. Bird (1961, 1962, 1965) considers that progradation of the outer barrier has now come to an end and that natural shoreline retreat is under way. Booran 1 land system covers all of the outer barrier, the Ninety Mile Beach being a component. A much lower foredune and beach system has formed in the reduced wave energy environment along the eastern shore of Lake Wellington, and is mapped in Booran 2 land system.

Sedimentation in the Lakes

The Gippsland Lakes are shallow coastal lagoons fed directly by six rivers (the La Trobe, Avon, Perry, Mitchell, Nicholson and Tambo) and several creeks. In addition, the La Trobe is joined by the Thomson and Macalister rivers just upstream from the Lakes. These streams have contributed most of the sediment to the Lakes although some has been derived from erosion of the marginal sea cliff and other features. Deposition has involved paludal, lacustine and estuarine/deltaic processes of accretion.

Swamps are a feature of the more sheltered shores, such as the southern shores of Lake Wellington, and delta margins, for example the estuaries of the Mitchell, Avon and La Trobe Rivers, and there is evidence that swampland encroachment has in the past reclaimed parts of the lagoon margins (Bird, 1961, 19963, 1965). However, much of the lake shore swampland has now been destroyed or is being cut back by waves following ecological changes associated with increasing salinity (Bird 1978) and other anthropogenic influences. Al existing swamps, including the major inland non perennial ones, have been mapped in Morass land system, the shoreline reedswamp being represented by one component.

Deltas protrude into the lakes at the mouths of most of the rivers and are mapped in Delta land system. They are essentially extensions of the natural levees that lie upstream. Their development has depended on the presence of a shoreline reedswamp fringe to trap river sediments and offer protection against wave attack (Bird 1961, 1963, 1965). Deltas still having shoreline reedswamp fringe, i.e. those of the La Trobe and Avon, are still growing but where the reedswamp has been destroyed, i.e. along the Mitchell and Tambo deltas, erosion is now well established.

The shape of the deltas varies with the characteristics of the river and of the lacustine depositional environment. The La Trobe, Avon and Tambo deltas, formed in relatively exposed parts of the lakes, have cuspate shape. There is no delta on the Nicholson, possibly partly due to drowning or recent erosion but possibly also because the Nicholson has been diverted from its earlier tract in Clifton Creek (VandenBerg 1981) and significant alluvial deposits have not yet accumulated along its length. The Mitchell delta is digitate (Figure 3.9), probably because of the relatively well sheltered nature of its position at the north-western end of Lake King (Bird 1961, 1963, 1965).

The Mitchell delta is unusual and has aroused some interest. Jenkin (1968) believes that it represents partially drowned levee remnants but bird argues that reported sea level fluctuations would have led to recent emergence rather than submergence of the silt jetties and cites evidence of their active prolongation before the erosion of the last few decades began.

Re-distribution of silty and sandy sediments across the lagoon floors and along the beaches has occurred by wave and current action, the movement tending to be in the north-easterly direction in response to prevailing winds. In places exposed and the resultant almost featureless low plains are in Clydebank land system. Exposure of these areas of lake floor has been due partly to Holocene tectonic (or eustatic) emergence and contraction of the lakes, partly to generally lower lake levels following the opening of a permanent entrance at Lakes Entrance and partly to a much older (Pleistocene) lagoon floor reclamation behind Bird's prior barrier between Strathfieldsaye and Goon Nure.

The Baragwanath Anticline

The Baragwanath anticline is a broad asymmetrical anticlinal fold, plunging gently to the east. It extends easterly from the elongated dome of Cretaceous sediments know as the Balook Block (Hills 1975) but here the Cretaceous sediments are overlain by coal measures with appreciable thickness of classic and organic sediments, and the Haunted Hills Gravels.

The present topography results from deep Plio-Pleistocene faulting and progressive uplift of the underlying Cretaceous sediments causing monoclinal movement (the Rosedale Monocline) in the overlying sheet of Tertiary deposits (Hills 1975, Jenkin 1968, Douglas 1976).

The Baragwanath Anticline sub-region is different from the eastern lowlands because of its elevation and slope and the very sandy nature of its soils. The anticline forms the drainage divide between the La Trobe River and Merriman Creek but since Merriman Creek lies to the south of the survey area, only the La Trobe River side of the anticline is considered here.

Two land systems have been mapped in this area. Gormandale land system dominates the slopes and has very sandy podzolic soils. Accumulations of ferruginous nodules and areas of hard sandy plinthite are common. Clay lenses also occur, but unpredictably. Sandy land system occurs on broad drainage floors with relatively steep downstream slopes. These floors sometimes function as local aquifers and, as a result, seepage zones on the lower slopes are common.

The sand deposits of the Baragwanath Anticline have been significant in past landscape development, providing a major sand source. The La Trobe River carried much sand into Lake Wellington, while to the south, Merriman's Creek transported some of the sand to the south-east from where it was subsequently carried by aeolian and marine movement into the survey area. These transported materials were the major source of sand for Perry and Barrier land systems in the Seaspray-Dutson area.

The Western Volcanic Plateaux

Volcanic activity during the Tertiary was relatively extensive in the western part of the study area. Earth movements subsequent to most of this activity raised some of the basalt so that outcrops of these Older Volcanics occur in both the lowlands and the uplands. All areas of Older Volcanics below the sub-alpine zone have been mapped in Neerim and Thorpdale land systems, irrespective of elevation. The largest areas of basalt occur near Warragul, Neerim and Thorpdale and most other occurrences are along the northern margins of the South Victorian Uplands and the southern parts of the East Victorian uplands.

The Warragul occurrence, overlying Devonian rocks, has been uplifted between the Darnum Monocline and the Heath Hill Fault. This area, termed the Warragul Block, has suffered less dissection than the other areas of basalt and consists of low rounded hills with intervening almost flat drainage floors. Most of the basalts in this area are in Neerim land system.

To the north of the Warragul Block near Neerim, similar volcanics also overlie Devonian rocks. However, this area is higher and has been more deeply dissected. The underlying Devonian sediments are frequently exposed in the incised drainage lines and in places the basalts have been completely removed. Land forms on the exposed Devonian sediments are similar to the rounded hills with intervening flats of the volcanic areas; this may be due partly to direct superimposition of the volcanic drainage pattern, and partly to some contact or diagenic alteration at the unconformity. The areas of exposed Devonian sediments are in Buln Buln land system.

Near Thorpdale, the volcanics (and the thin underlying Childers Formation) overlie Cretaceous sediments of the Strzelecki Group. They occur in part of the Narracan Block which was uplifted in Plio-Pleistocene times between the Yarragon Monocline and the Mirboo Fault. The volcanics in this area are deeply dissected and mass movement has been a pronounced denudation process in the regolith. No active landsliding was observed and most previous landslide debris has apparently been removed by the drainage system.

It is not certain how old the landslides are or what caused them, but tectonic shocks that may still be going on in the Strzeleckis (Hills 1975), the clearing of timber after land settlement and the application of irrigation water are likely to have been contributing factors. Areas of basalt subjected to landslide activity have been mapped in Thorpdale land system.

Soft, deeply weathered basalt occurs over most of the volcanic areas and has affected the nature of the soils (Chapter 4). In some places, however, such as north-west of Glenmaggie, there is no deeply weathered regolith and the soils formed on fresh basalt have different characteristics.

In the south-eastern part of the Narracan Block, near Delburn, a quite different dissection pattern and soil association occurs on the volcanics. The basalt here seems to be completely weathered and replaced by rubbly plinthite with lithosolic soils. Most of this complex area has been mapped as Delburn land system.

Important aquifers occur in and under many areas of volcanic rock (Nahm 1977). In the Thorpdale area where sands of the Childers Formation immediately underlie the volcanics, abundant good quality groundwater is available. In this and other areas, groundwater emerges as permanent springs in some drainage floors, most of which are mapped in Morass land system.

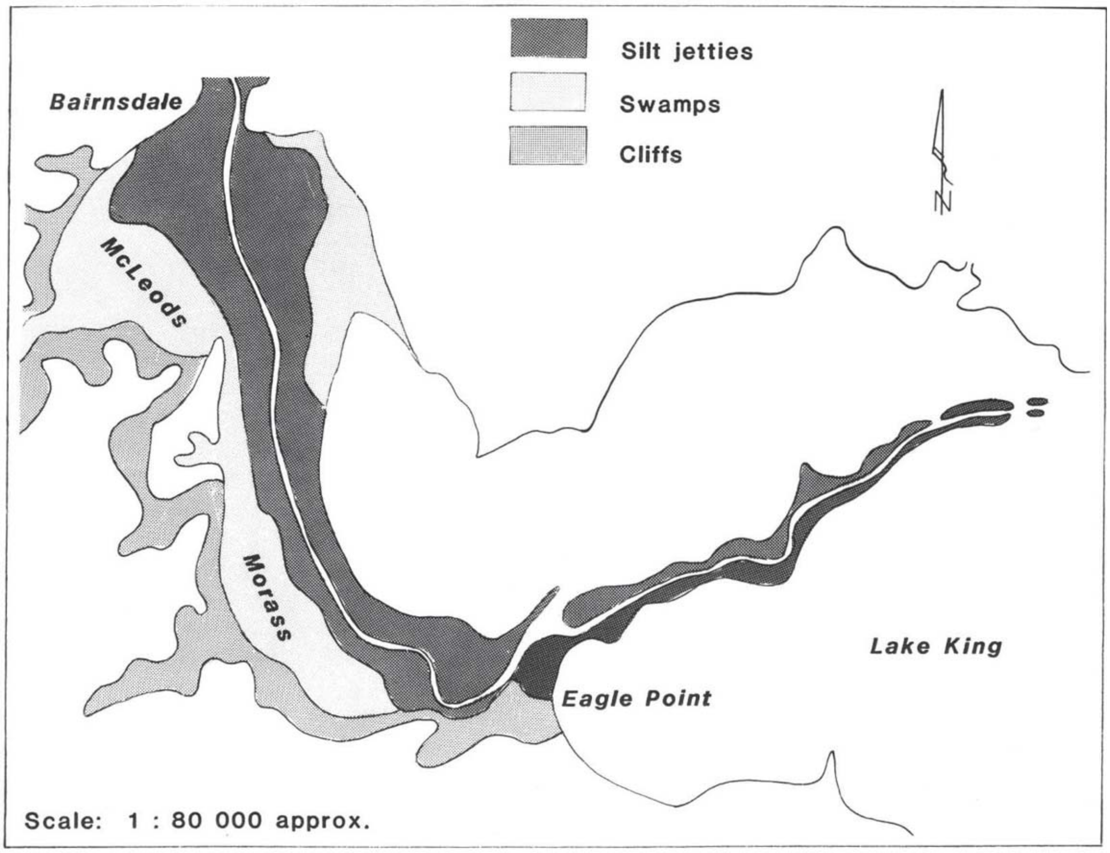


Figure 3.9 – Orientation of Mitchell River silt jetties below Bairnsdale.

The western lowlands

This are differs from the eastern lowlands because of its more humid climate and the different surrounding rock formations that have provided parent materials for its soils. These rocks include large areas of Older Volcanics and the sedimentary Cretaceous Strzelecki Group. Structural complexity is also a feature.

Structurally, a range of low hills in the vicinity of the Haunted Hills and Tanjil Faults (between Moe and Yallourn) subdivides the area. To the west of these low hills the Moe, La Trobe and Tanjil rivers have deposited broad plains of alluvium in what was once a swamp basin (Hocking 1976) known as the Moe Sunklands (Jenkin 1968), and now drained by the Moe Drain. These deposits and the soils formed on them are gleyed and distinctly hydromorphic; they are mapped in Moe land system.

The swamp deposits are flanked on the south by a broad colluvial apron (Trafalgar land system) built up of detrital materials from natural erosion of the Strzelecki Ranges over a long period (figure 3.10). These deposits are ochreous at depth, porous and clearly better drained than the alluvium of Moe land system but they do have somewhat hydromorphic soils.

East of the low hills, channelised drainage and slightly lower rainfall prevail but the soils and their parent materials show affinities with those to the west. The modern flood plains are in Mow and Thomson land systems. The relict flood plains of Yinnar land system, a variant of Valencia land system, have mottled soils with locally impeded drainage. Similar hydromorphic soils occur on the Morwell and middle La Trobe river flood plains (Traralgon and Thomson land systems).

Throughout this sub-region dissected Tertiary fans and flood plains, as described in the eastern lowland sub-region, are widespread; these are mapped in Anderson 2 or Westbury 2 land systems depending on the degree of dissection.

The Geomorphic Provinces

A geomorphic province is an area within which the major current landscape forming process or processes are essentially similar in terms of both type and balance. Difference in processes or process balance rather than in land morphology is the important criterion in distinguishing between provinces, although the processes operating can sometimes be inferred from the land morphology.

Factors which cause differences in processes or process balance include the rejuvenation of some streams by uplift, stream capture or local base-level change; an influx of sand or other highly permeable material inhibiting run off; the etching out of structures such as resistant metamorphic aureoles in generally softer rocks; and local variation in the erosive impact of climate.

It is important to distinguish between genesis of a land form and the landscape forming processes currently affecting it. Land form may be antecedent and therefore misleading with respect to present processes; for example, a change in stream course, as may occur following stream capture, may render once active fans, flood plains and deltas relict and erosion may replace deposition as the principle landscape forming process.

The provinces have been divided into sub-provinces on the basis of local factors. The definitions and descriptions of the provinces and sub-provinces are set out in Table 3.3. the provinces are designated G for Gippsland plus a number, e.g. G1, G2, up to G7.

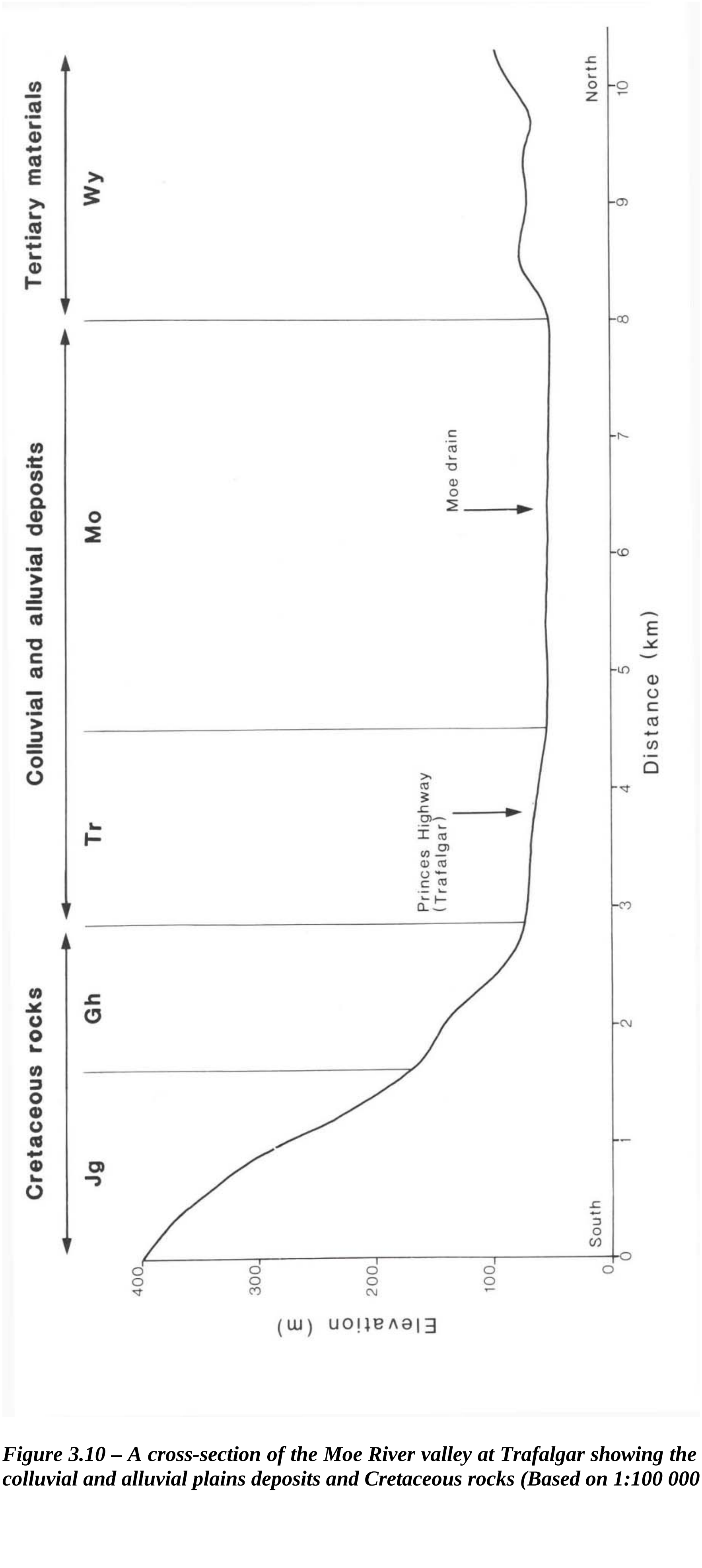


Figure 3.10 – A cross-section of the Moe River valley at Trafalgar showing the relationship between colluvial and alluvial plains deposits and Cretaceous rocks (Based on 1:100 000 topographic map).

Table 3.3 – Definitions and descriptions of the geomorphic provinces and sub-provinces

Balance between slope and stream processes is critical factor in landscape development

Erosional landforms – mountain , hilly and sloping terrain

- G1 The capacity of slope processes to supply erosion products is less than the capacity of the streams to remove them
  - G1a Relatively erodible rocks
    Characterised by rapid rates of stream incision, ridge and ravine topography, shallow stony soils, exposed rock, clearly evident soil creep, and no significant valley deposits. Base level is effectively lake level
  - G1b Erosion resistant rocks
    Characterised by slow rates of stream incision, convex "plateaux", much outcrop of resistant lithologies, and little soil. Minor storage of colluvium in bogs behind structural barriers occurs in some land systems. Base-level is effectively lake level. This sub-province, occurring mostly at high elevations, could be regarded as a special case of G1, with structural control of form
- G2 The capacity of slope processes to supply erosion products approximately equals the capacity of the streams to remove them
  - G2a Stream gradients principally determined by the prior land surface; potential for stream entrenchment Characterised by "plateaux" and sloping land surfaces of relatively low relief, mostly at high elevations. Drainage networks are weak and typically orientated normal to the regional slope of the land and the direction of the major external streamlines, although in some areas it is structurally controlled. Storage of colluvium can occur along minor stream sections where the stream gradient is locally reduced, for example, where rocks are more erosion resistant.

    These areas are generally variously dissected prior landscape remnants, not yet significantly encroached upon the current wave of stream entrenchment.
  - G2b Stream gradients principally determined by proximity to ultimate base level. Characterised by low rounded hill, dissected slopes and undulating flow.
  - G2c The capacity of the regolith to absorb rainfall almost precludes surface flow. Characterised by rounded hills and valleys on basalts.
- G3 The capacity of slope processes to supply products is greater than the capacity of the streams to remove them
  - G3a Low stream gradients on erosion resistant rocks reduce the capacity of streams to remove material. Characterised by plateaux at higher elevations with valleys with colluvial and alluvial fill and sometimes also with peat accumulation
  - G3b Low stream gradients on prior land surfaces reduce the capacity of streams to remove material. Characterised by plateaux at higher elevations with valleys with colluvial and alluvial fill and sometimes also with peat accumulation
  - G3c Low stream gradients, due to outcrops of erosion resistant rocks which form local base-levels, reduce the streams capacity to remove material. Characterised by plateaux, hills and undulating terrain with accumulations of alluvium and colluvium on lower slopes due to the presence of downstream metamorphic aureoles or other erosion resistant rocks which form a barrier to stream incision.
  - G3d Cause of process balance unknown. Characterised by rounded hills and undulating terrain with broad, alluviated swampy valley floors with little channelised flow.

Balance between deposition and erosion by Littoral, Paludal or Fluvial processes is critical factor in landscape development

G4 Deposition and erosion both occur

G4a Fluvial processes. Characterised by the modern river flood plains, with active river channels and flow paths and some active colluvial aprons of low slope. In this terrain, processes of aggradation and erosion both occur and one may dominate, the dominance changing over time as the rivers work their flood plains and respond to tectonic, eustatic, and other changes.

G4b Littoral processes. Characterised by the Holocene littoral strip with beaches, berms, foredunes and other coastal land forms. Both marine and lacustrine frontages are included.

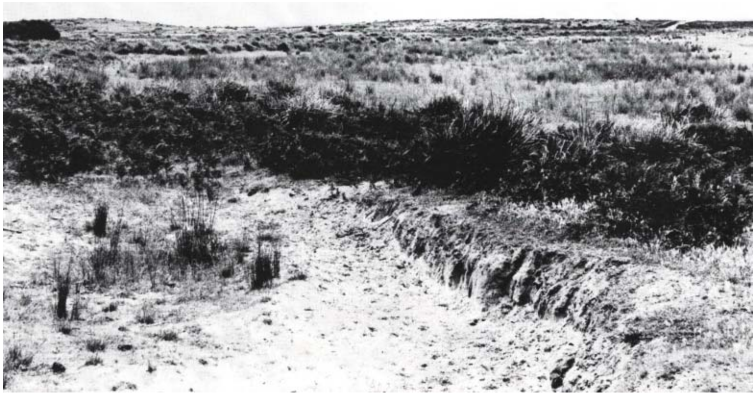
G5 Deposition more effective than erosion. Paludal and fluvial processes. Characterised by river levees and deltas and low lying swampy plains, often adjacent to the lakes.

Depositional and erosional processes relatively inactive, resulting in little landscape modification

Mostly the late Tertiary and Pleistocene coastal and alluvial plains; also the Pleistocene sand deposits

G6 Gentle terrain and elevation above flood plains almost preclude erosion and deposition. Characterised by almost flat sloping plains with little drainage incision. These plains were almost flat when formed by fluvial and lacustrine processes in the late Tertiary and Pleistocene. The youngest Pleistocene terrace included still has remnant levee channel systems (Briagolong land system) which have suffered little erosive alteration. The recently exposed areas of lake floor are also included in this province.

G7 Erosion and deposition relatively inactive due to the capacity of the regolith to absorb rainfall and to stabilization by vegetation. Characterised by unconsolidated sand deposits of mainly Pleistocene age, situated in the main rain-shadow area of Gippsland.

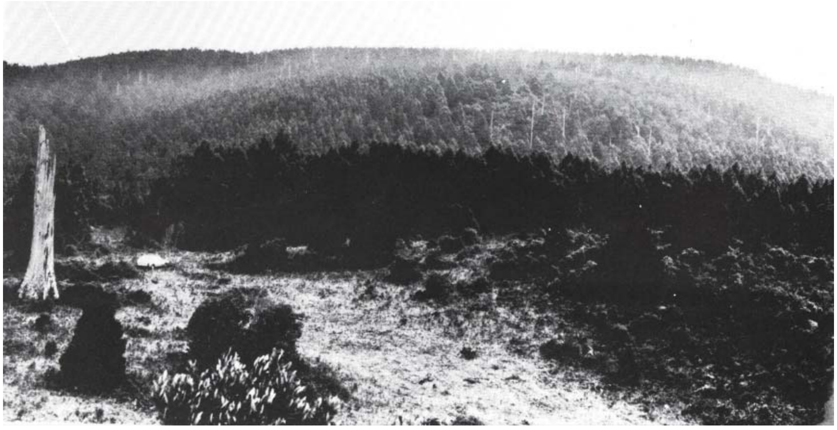


Sand sheets and low dunes near the Gippsland Lakes occur in Province G7

The boundary between terrain with deeply incised rivers in Province G1a and terrain where entrenchment has been limited by erosion-resistant rocks in G1b.

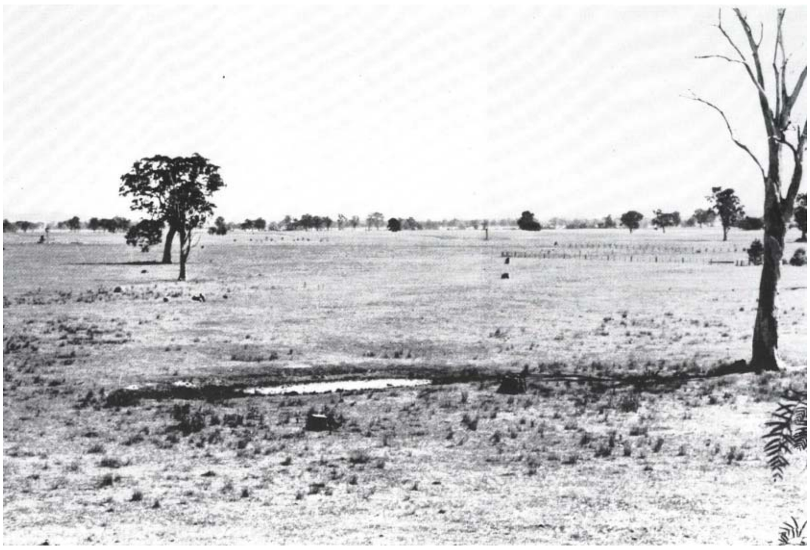
Erosion-resistant rocks in Province G1b have prevented the deep entrenchment of modern streams so that the terrain is hilly to undulating.

The low rounded hills of Livingston land system in Province G2a are part of a prior land surface at high elevation, as yet unaffected by stream entrenchment following the Plio-Pleistocene Kosciusko uplift.



Gentle undulating surface of the Baw Baw plateau in Province G2a

The low hills and rounded valleys of the Tambo land system in the foreground are in Province G2b while steeper slopes with V-shaped valleys are characteristic of the ridge-and-ravine terrain in G1a.



The almost flat surface of the earlier Pleistocene terrace in Province G6.

A small scarp marks the junction between the earlier and later Pleistocene terraces near Briagolong, both in Province G6.

The outer-barrier, Province G7.

Looking northwards towards Rotomah Island with Lake Reeve and Sperm Whale Head in distance.

4. SOILS

Introduction

The soils within the catchment to the Gippsland Lakes are divers, reflecting the great variety of rocks and unconsolidated sediments, landforms, climates and vegetation, as well as varied ages of soil development.

In this chapter the soils are discussed in their geomorphic, lithologic and pedogenetic setting in order to consider their nature and behavior both under natural and modified conditions. Before discussing individual soils, however, soil formation and its relationship to classification are briefly considered following the concepts of Paton (1978).

Soil Formation

Soil formation can be divided into two phases:

(i) the production of a mantle of mineral particles by rock weathering and/or deposition and
(ii) changes in the characteristics of this mantle, for example in colour, pedality, fabric, texture and consistence, and the development of horizons through vertical differentiation of the characteristics. Northcote (1976) refers to such changes as ‘pedologic organisation.

Weathering, leaching and new mineral formation

Paton combines the processes of mineral weathering, leaching and new mineral formation under the term of epimorphism. They are the processes b which rock and cemented sediments disintegrate to from the mineral component of soil mantles. They continue to operate, however, once a soil mantle has developed.

Weathering

The driving force for the weathering of any mineral is its innate tendency to adjust to a change in ambient conditions.

Primary minerals such as feldspars, amphiboles, pyroxenes, quartz and micas are formed deep I the earth’s crust at high temperatures and pressures and in the absence of oxygen and water in the liquid state. When exposed to the very different conditions at the earth’s surface, most primary minerals become unstable and undergo chemical and physical alteration to from secondary minerals of lower density.

The rate of weathering and secondary mineral formation varies with temperature and composition of the surrounding solution, as well as with the resistance to weathering of primary mineral. Quartz, especially if larger than silt size, and certain accessory minerals such as zircon, rutile and tourmaline, are very resistant, while amphiboles, pyroxenes, biotite mica and the calcium feldspars weather rapidly.

Sedimentary rocks are usually composed of clay-sized secondary minerals and resistant primary minerals, mainly quartz, derived from older rocks. The secondary minerals, having formed from primary minerals at the earth’s surface, are more in equilibrium with the surrounding conditions and tend to undergo further chemical alteration only slowly. However they are more weatherable than the quartz. Therefore, under climatic conditions such as occur in the study area, initial weathering of sedimentary rocks largely involves removal of mineral cementing substances between the particles. In this way a hard consolidated mass disintegrates into a soft soil material. Other factors being equal, the sedimentary rocks tend to have shallower soils than he igneous rocks which contain unstable minerals such as micas and feldspars.

Leaching

Leaching involves the movement of mobile weathering products with percolating water. Ca, Na, Mg and K ions are highly mobile when released from minerals. Iron in its ferric (most oxidised) form is essentially immobile, but in the ferrous state it is slightly soluble and can diffuse in water or move it. Si and Al ions, which tend to co-precipitate close to the point of release and to be rearranged into new minerals, are not easily lost.

Severe leaching reduces the concentration of mobile products in the upper part of the weathering zone. As a more dilute solution results in more rapid weathering, rocks tend to weather more rapidly in high rainfall areas where the greater volumes of water available promote leaching.

New Mineral Information

New, or secondary, mineral formation is the inevitable result of weathering and leaching. Secondary minerals arise not only from the alteration of primary minerals, but also from the precipitation of leached soluble or colloidal substances.

Many minerals in the clay fraction of soils, for example kaolinite, illite and montmorillonite, are formed from a whole range of primary silicate minerals. These secondary minerals can also be further weathered.

Lateral surface movement

Lateral surface movement of rock fragments and soil takes place in response to the earth's gravitational and atmospheric forces. When movement is by water or wind, the particles are inevitably sorted before being redeposited. In mass movement such as soil creep, landslide and mudflow, materials are not sorted and, in the case of mudflow, can become quite mixed.

In the study area, lateral surface movement affects most of the land in some way. For example, beach sand has been blown landwards over considerable distance and sheet erosion occurs as a normal geologic process in most hilly and mountainous areas. Here soil creep and landsliding also occur.

Lateral surface movement is very significant in soil development. Often it provides the mantle, as in dunes and on flood plains, in which soil differentiation occurs. Where removal exceeds deposition, shallow soils occur. In other instances it may modify soil texture as when sand becomes incorporated into a clay profile formed on basalt through surface wash from adjacent terrain.

The degree of particle sorting also affects several processes of soil development and profile differentiation. For example, coarse sands are permeable and have low cation exchange capacity. The promotes leaching, acidification and mobilization of iron-humus complexes, and the development of Podzols with their bleached A_2 and brown or black coffee rock horizons. Podzols do not form in sediments containing a significant proportion of clay.

Biospheric reactions

Plants and animals react with soils in many complex ways, wither accelerating or retarding the processes of epimorphism and lateral surface movement. For example, respiration of roots and decomposition of organic matter produce carbon dioxide and organic acids which tend to increase soil acidity. This in turn accelerates the weathering of minerals and changes the solubility and hence mobility of Si, Al, Fe and most trace elements. On the other hand, living vegetation cycles nutrients back to the surface and produces humus which, with its high cation exchange capacity (CEC) reduces the leaching of Ca, Mg, K, Na, and other cations. Humus also increases soil water holding capacity and this further tends to reduce leaching by reducing the amount of percolating rainwater. The net result of all these factors will vary from one ecosystem to another.

Vegetation retards lateral surface movement of soil by providing protection from wind, raindrop impact and runoff. It also reduces soil water levels and thus the risk of mass movement. Tree throw and burrowing animals, however, have the opposite effect and can significantly increase the rate of downslope movement of soil or the mixing of soil materials, a process called bioturbation.

Vertical differentiation of soil profiles

Epimorphism, biospheric reactions and lateral surface movement act with unequal intensity at different soil depths. Thus soil profiles are generally layered. For example, topsoils are usually darkened by organic matter accumulation and subsoils are often mottled or gleyed due to water-logging at depth.

The degree and type of differentiation depends on the age of the soil as characteristics vary in their rate of formation. For example, the accumulation of organic matter and the coating of iron oxides on particles, both of which increase inter-particle bonding, can take place more rapidly than textural changes or ped formation in subsoils.

Water is involved in many of the processes so that differentiation is limited in dry areas. Soil development is also reduced when the materials are mixed, as in the process of bioturbation.

The development of horizons results from processes operating both vertically and laterally. An example of a vertically operating process is leaching in a well-drained soil. Percolating rainwater usually removes soluble constituents more readily from the topsoil than from the subsoil and, although countered to some degree by the raising of nutrients from the subsoil by deep-rooted vegetation, often results in higher concentration of nutrients at depth.

Downslope movement of sandy material and its deposition over a clay to produce horizons of different texture is an example of a lateral process.

Soil formation and classification

Broad relationship between soil forming conditions and the characteristic morphologies of soils in the catchments can be expressed well in terms of Northcote's (1979) soil classification, which is based at the broadest level on texture differentiation.

Soils of uniform texture (U) are typically found on unconsolidated sediments which are highly sorted or too young for differentiation to have occurred. They also occur in geomorphologically active environments where soil materials are continually mixed, for example on steep slopes.

Differentiation is more pronounced where little mechanical disturbance occurs and where chemical weathering and leaching are unimpeded. Thus gradational (G) and duplex (D) soils are found in landscape positions where bioturbation is minimal, such as under sparse vegetation, and where landslips are absent. Duplex soils, with strong texture differentiation, characterize older stable surfaces such as the Pleistocene alluvial plains. Gradational profiles have a gradual increase in clay content with depth, and they tend to occur on slopes of intermediate stability.

A further group, the organic soils (O), have a high organic matter content. They are found in environments where oxidation of accumulated organic matter is limited by water-logging, as in swamps. Low temperature is an additional factor limiting oxidation in alpine and sub-alpine areas.

Individual soils of catchments are discussed in the following sections in order of increasing pedologic organization as reflected by texture differentiation. This is generally associated with a differentiation in colour, fabric, structure and other features, the main exception being the soils known as Podzols (*Stace et al* 1968) which are highly differentiated in colour and chemical properties but which have uniform texture profiles.

Calcareous Sands of the ocean beach and coastal foredunes appear to have no pedologic organization. The sands of coastal rear dunes and of beaches and dunes associated with the Lakes are similar but appear to have lost the calcium carbonate of the original sediments. Organic soils of bogs and swamps also have weak organization, except for blackening of topsoil organic matter through oxidation. Uniform textured soils of mountains and steep hills, as well as those of lake margins and the youngest river terraces, have minor pedologic organization, exemplified by surface organic matter accumulation, some colour differentiation between horizons and sometimes weak pedality.

Gradational soils are regarded as having a moderate degree of pedologic organization having developed a vertical textural trend, presumably over a considerable time span. Although they have greater pedologic organization, they often intermingle with uniform profiles in the mountains and steep hills.

Here, soil stability appears to vary over short distances in response to factors such as infiltration capacity of soils and vegetation density.

Duplex soils and uniform sandy soils with bleached A2 horizons and prominent translocated iron and humus accumulations (Podzols) are considered to have the highest degrees of organization.

The Major Soils within the Gippsland Lakes Catchments

Data in the following section is based on the description of soil profiles during field work and on laboratory analysis of samples taken from seventy sites considered representative of the major soils. Samples for laboratory analysis were taken from undisturbed sites whenever possible. Where sites in pastures or cropland were samples, the results were interpreted in the knowledge that cultivation, grazing and/or the use of fertilizers are likely to have had an effect on some physical and chemical properties. Analyses covered a range of properties relevant to fertility, mechanical behaviour and genesis of soils.

Soils with little or no pedoligical organization – uniform and organic soils

Sands of the ocean beach and foredune

(i) Environment

The coastal foredune, berm and beach consist of sands with fine shall fragments. In the least protected sites, that is on the beach, berm and seaward-facing slope of the foredune, the waves and wind intermittently erode, deflate and redeposit the sands. Pedologic organisation is thus shortlived as the materials are repeatedly homogenized.

The landward facing slopes and some crests of foredunes are less frequently disturbed allowing some profile development.

(ii) Appearance and classification

In the most dynamic areas, the profile appears to be a uniformly light yellowish brown or very pale brown sand. Close examination shows that shell grit and dark brown, black and reddish mineral grains, which can weather further, are mixed with the white and yellow inert quartz sand. There is no visible organic matter at the surface.

In less dynamic sites, organic matter has accumulated to produce a dark topsoil and there is a greyish brown subsurface.

All such sands are classified as Ucl. 11 by Northcote (1976) and as Calcareous Sands in the system of Stace *et al*. (1968)

(iii) Chemical and physical analyses

The sands are mostly alkaline due to calcium carbonate (lime) in sea shells. In the analysed profile, the topsoil pH (6.2) was less than that in the subsoil (8 to 9) indicating mild leaching of calcium carbonate. The organic carbon level of the topsoil was 4.4%, representing about 7.5% organic matter and this increases the CEC which was 15.7 m.e/100g soil. Exchangeable Ca, Mg, K and Na are held by the organic matter and are thus protected from leaching. Below the topsoil, organic matter levels, CEC (<4 m.e/100g soil) and exchangeable cations decline dramatically.

(iv) Argonomic features and factors affecting processes of deterioration

The lack of organic matter or of cementation by precipitated lime renders the sands loose. The paucity of small particles between larger grains results in high filtration capacity and permeability while the lack of fine pores leads to a low water-holding capacity.

Analysis of similar sands elsewhere (Northcote *et al*. 1975) indicate likely deficiencies in trace elements, and also K, Nm and P, resulting from the chemically inert nature of the quartz.

The looseness of sands makes them highly erodible by waves or, when dry, by wind. However, the high infiltration capacity limits run-off, so that apart from the transporting effect of raindrop splash, there is little water erosion. The sands are liable to loose any cations by leaching if released from surface organic matter, for example by burning, or if added in fertilizers.

Sands of coastal rear dunes and of beaches and some dunes associated with the Lakes

(i) Environment

Read dunes behind the coastal foredune (Booran1) and some sands on beaches and dunes associated with the Lakes, that is those mapped in Booran 2, and parts of Clydebank, Rotomah and Seacombe land systems, are also in geomorphically active environment although the forces of wind and water are less than those along the ocean front.

The sediments have been transported and deposited by waves and wind and hence are highly sorted. As a result the sands are generally devoid of bonding clay.

The lack of pedologic development is due to continual mixing by wind and waves or, in areas that are now stable, to youthfulness and inertness of the parent material.

(ii) Appearance and classification

The sands have slight accumulation of surface organic matter and are usually deep, with little or no coherence (Ucl.2, Siliceous Sands). Coherent and firm sands (Ucl.4) occur in some localities.

(iii) Chemical and physical analyses

No profiles were analysed but field observations indicate that, unlike the sands of the ocean beach and foredune, the calcium carbonate has been leached from the root zone.

Field pH tests indicate that the entire profile is usually only slightly acidic to neutral in spite of the extremely low levels of cations such as Ca, Mg, K and Na. The low cation levels reflect a low CEC which is due to inertness of the sands. P and N are also extremely low.

(iv) Agronomic features and factors affecting processes of deterioration

Infiltration capacity and permeability are high but water holding capacity if very low. Inherent nutrient levels are probably lower than in the calcareous sands. Low fertility combined with droughtiness restricts plant growth, resulting in low organic matter production. Low humus content in turn retards the development of soil conditions more suitable for plant growth.

Exposed sands are very prone to wind erosion when dry and their low fertility exacerbates the problem by limiting the re-establishment of vegetation. Added nutrients can be lost readily by leaching. Water erosion is not significant due to high infiltration capacities.

Organic soils of bogs, swamps and hillside seepage zones

(i) Environment

Bogs, swamps and hillside seepage zones usually have water tables at or near the surface. The resultant low oxygen concentration results in organic matter accumulating more rapidly than it is oxidized. The water table may rise as the organic layer thickens allowing the formation of peat layers of considerable thickness.

Being in low situations, the soils tend to accumulate water and leaching and erosion products derived from surrounding land.

Saturation limits development of structure and fabric of associated mineral layers. It also produces strong reducing conditions and this is reflected in the light or dark grey colours. The high organic matter content and reduced percolation of water limits texture differentiation.

(ii) Appearance and classification

The organic soils consist of black peaty material, which may be distinctly fibrous at the surface and usually 0.3 m to 0.7 m in depth. Where it is shallower there is often a considerable admixture of mineral particles.

The organic layer overlies mineral sediments of variable texture and composition. In Baw Baw land system on granodiorite, the sediments are coarse textured and contain much feldspar, quartz and white mica while in Booran 2 the substrate is lacustrine fine quartz sand, and in Delta it is mixed alluvium.

The deeper peaty soils meet Northcote's definition of Organic (O) (Northcote *et al.* 1975) and are Acid Peats according to Stace *et al* (1972). The shallower and often less organic soils are mostly Um7.12 (Humic Gleys).

(iii) Chemical and physical analyses

The most significant property is the high content of organic matter which imparts low mechanical strength but high water-holding capacity, particularly in the more fibrous peats.

Samples of organic soils from sub-alpine bogs (Baw Baw) and drained lowland swamp (Moe) are relatively high in available P compared with surrounding soils which have not been fertilized. Estimates of base saturation were 1 to 5% at Baw Baw but 10 to 27% near Moe. It is interesting to compare these values with those for topsoils on slopes draining to the bogs <1% at Baw Baw and <3% near Moe. The higher base saturation in the bogs is probably due to accumulation of bases leached from surrounding land. In alpine and sub-alpine areas with very high rainfall, however, such accumulation is likely to be less than that at lower elevations due to the more highly leached nature of adjacent soils. Organic soils in riverine or coastal swamps would have varying degrees of base saturation, depending on the composition of the incoming water.

High levels of exchangeable hydrogen associated with high CEC produces acidic conditions, even where base saturation approaches 30%, as in Moe.

(iv) Argonomic features and factors affecting processes of deterioration

Organic soils can store large amounts of water. The organic material, however, for example is prone to oxidation if the water table is lowered, for example by artificial drainage for agriculture. Overseas measurements indicates that soil loss rates due to oxidation of drained peats can be three orders of magnitude greater than accumulation rates. That is, peat soils which have taken ten thousand years or longer to develop can disappear on drainage in a few decades. Also, exposed dry peats are prone to wind erosion due to their very low specific gravity and the ease with which they are pulverised.

Due to their high water content and low mechanical strength, organic soils are also extremely vulnerable to compaction. The damage due to hoop pressure from grazing cattle is well documented.

Soils in well-drained alpine and sub-alpine areas

(i) Environment

Low temperature at high elevation reduce rates of chemical weathering and biospheric processes. This may largely explain the lack of profile development, even on stable gentle slopes. Another possible explanation is mixing mass movement under relatively recent periglacial conditions.

Under high rainfall and low temperatures, soil organic matter is formed more rapidly that it is oxidised. Consequently locally deep, strongly acidic topsoils with high organic matter content are characteristic of alpine and sub-alpine areas.

(ii) Appearance and classification

Profiles are generally stony and shallow, and textures vary from loamy sands to loams depending on parent material. A2 horizons are absent and Factual Key designations are mostly Um6.1, Um6.2 or Um7.1. Great Soil Groups include Alpine Humus Soils, Lithosols and Brown Earths.

(iii) Chemical and physical analyses

The soils are amongst the most strongly leached in the study area, with base saturation often below 1% and pH values between 4 and 5. Measured organic carbon contents ranged from 6.6 to 13.6% in the topsoil and up to 5% or more at depths of 30 cm. Available P ranges from 12 to 26 ppm but values are higher (80-90 ppm) on basalt. Available K varied from 70 to 180 ppm.

Infiltration rates are likely to be high although the organic matter is hydrophobic and tends to shed water when dry. Under dry conditions, however, preferential water entry via *Poa* tussocks has been observed. Permeability is also high, partly due to channels caused by the decomposition of roots.

(iv) Argonomic features and factors affecting processes of deterioration

The highly leached nature of the soils and extreme acidity are dominant factors limiting productivity. Low temperatures and exposure to strong winds further limit the potential for plant growth.

The organic topsoils are prone to wind erosion when exposed and dry. When wet, compaction is a potential problem, high organic matter content and high porosity reducing shear strength and bearing capacity. The high topsoils CEC and low base saturation reduce the leaching of cations.

Soils of mountains and steep hillslopes

(i) Environment

Only low to moderate degrees of pedologic organisation are characteristic of soils in this environment due to continual mixing of the soil by slope processes and bioturbation.

These processes vary intensity. The steeper gradients and longer slopes tend to produce larger volumes of run-off, faster flow rates and hence more soil loss. On the other hand, such losses are reduced where there are deep permeable soils and dense protective vegetation. Forest fires are another variable factor affecting soil stability. Soil inversion by tree throw is more common in shallow soils, deep soils providing better anchorage.

As a result of this variability, profile development varies, even on slopes in the same general environment, and uniform and gradational profiles occur in close proximity.

(ii) Appearance and classification

Bioturbation and erosion are generally severe enough to lead to a predominance of soils with uniform texture and little other differentiation. Textures may be sandy (Uc), loamy (Um) or clayey (Uf) depending on parent material. On sandstones or quartzites, shallow stony Uc soils are the most common. Um soils predominate on shales or igneous rocks with abundant silt and clay forming minerals. Uf soils are usually confined to the Strzeleckis (Jeeralang, Gunyah, and Livingston land systems). And limestone (McAdam land system).

These texture groupings can be further subdivided according to type of pedologic organization, as summarized in Table 4.1

Many Uc and Um and son Uf soils are shallow and stony and may be turned Lithosols regardless of the variable organisation. Others may be termed Brown, Yellow or Red Earths depending on the dominant subsoil colour. A few Uc soils fit the description Earthy Sands.

(iii) chemical and physical analyses

Most of the soils are strongly leached, as shown by pH values of 4.2 to 5.0 and by low base saturation in the 8 profiles sampled. Base saturation is generally less than 3% in the topsoil and may increase to about 6% in the C horizon. Soils in the Strzeleckis appear to have somewhat higher values, possibly related to a greater concentration of bases in the parent rock. An Earthy Sand from Anderson 1 land system and a Terra Rossa from Salt Creek land system also have considerably higher base saturation due to factors such as lower rainfall and hence reduced leaching, and to lime-rich parent material.

Organic carbon content in the topsoil ranged from 1 to 6%. The upper subsoils contained 3 to 4% organic matter at higher elevations. Available P generally ranges from, 10 to 20 ppm and available K from 100 to 240 ppm; available K was 2 to 3 times higher in soils from the Strzeleckis.

Local infiltration capacity and soil permeability were not measured. However, data are available elsewhere for deep soils with dense vegetation (Bren and Turner 1979, Talsma and Hallam 1980). These indicate that infiltration capacity and surface soil permeability under these conditions are extremely high and that as a result, overland flow is low under nearly all rainfall events. For example, Bren and Turner found near Myrtleford, that the proportion of rainfall reaching the stream as overland flow was always below 0.5% and usually below 0.1%. Only an extremely intense storm would cause surface run-off.

(iv) Argonomic features and factors affecting processes of deterioration

Inherent nutrient levels are affected by parent rock while total available water-storage capacity varies with soil depth, structure and texture. Fertility tends to be adequate for forestry on most of the deeper soils even though they are well leached, probably due to the large volumes of soil accessible to tree roots. The potential for nutrient decline in the long term following timber harvesting and burning needs to be assessed.

Agricultural productivity is considered only in terms of pastures, the long, steep slopes precluding cropping. Pasture productivity is limited by the fixation of nitrogen by legumes and this in turn, depends on the availability of the P. The content of P is inherently low to moderate and added P rapidly becomes unavailable due to high acidity. In addition NO_3, an anion not held by cation exchange surfaces, can be leached readily from most soils due to their high permeability. Consequently pasture productivity tends to be low and can be increased only with considerable inputs of phosphatic fertilizers and lime, capital and labour.

Erodibility by water varies according to factors such as soil permeability and water-holding capacity. Although most soils are strongly leached, the relatively high CEC associated with high organic matter levels and the common loamy or clayey textures, is likely to reduce and further loss of cations. Soils with high organic levels and fine textures are prone to compaction, particularly when wet.

Soils of Holocene sediments and poorly drained areas of Pleistocene terraces

(i) Environment

Soils on the Holocene sediments have developed in an active or recently active depositional environment. The sediments deposited by fluvial processes are highly sorted and, where depositional conditions have changed over time, texture stratification is common.

Youthfulness has limited profile development and most soil variation is caused by differences in factors such as drainage status, source rocks, climatic conditions which range from sub-alpine to maritime, and stream regimes.

In depressions on the Pleistocene terraces, poor drainage has limited soil development through lack of leaching, bioturbation, oxidation and drying fractures.

(ii) Appearance and classification

Pedologic organization is limited mainly to the accumulation of surface humus although there is some development of pedality in the older soils with loam or heavier textures and/or higher organic matter contents. Mottling occurs where drainage is impeded.

The most commonly recorded soils are set out in Table 4.2.

These soils are regarded as Alluvial Soils and Siliceous Sands if they are not poorly drained and have little or no mottling. Some coherent sandy soils with an earthy fabric can be classified as Earthy Sands, while loamy soils with coherent porous fabric and stronger subsoil colours are included with Red, Brown or Yellow Earths. Where drainage is poor and mottling strong, the soils are Wiesenboden and Humic Gleys. Prairie Soils have relatively high surficial levels of organic matter, as slightly acidic to neutral pH and little or no mottling. These occur mainly on the younger flood plains.

(iii) Chemical and physical analyses

General statements are limited by the few analyses performed and by the variable sediments and environments. Profiles analysed were located only on major flood plains or terraces at low elevations in Maffra 1, Thomson, Delta, Stratford, Nambrok and Walnut land systems. Medium to moderately high base saturations were recorded ranging from 35 to 65% in the topsoil and commonly higher in the subsoil. Ca is the dominant ion in topsoils and sometimes throughout the profile. In Maffra 1, Delta and Nambrok land systems subsoils tended to become strongly to very strongly alkaline, with high levels of exchangeable Na and/or Mg. In Nambrok, alkaline subsoils were recorded at little more than 0.3 m depth but in Maffra 1 and Delta they usually occurred below about 0.6 m. this alkalinity reflects the presence of shallow saline water tables.

The sampled profiles were located in pastures or cropped areas and generally had moderate to high levels of available P and K, commonly 15 to 80 ppm and 200 to 600 ppm respectively. These levels may be higher than floors within the high rainfall, mountainous parts of the catchment would probably have low base saturations and low pH, comparable with the soils on adjacent slopes. None were analysed in the laboratory but this is indicated by field pH tests.

Water-holding capacities and mechanical strength vary widely, depending largely on texture and organic matter contents.

Table 4.1 – Major uniform soils of mountains and steep hillslopes

Northcote classification	Pedologic organisation and soil features	Occurrence
Ucl. 4- Um1.4-	Coherent, non-calcareous soils with little pedologic development and weak accumulation or organic matter in the topsoils	Common throughout mountains and steep hills on most rocks; least developed soils more common on drier aspects.
Uc4.1- Um4.2-	Coherent soils with a non-bleached A_2 but no B horizon (UC4.1) or apedal porous B (Um4.2).	
Uc5.2- Um5.4- Um5.5-	Coherent soils, weak horizon development, some fabric development but few, if any, peds; solum porous or dense.	
Um6.1- Um6.2-	Coherent soils lacking in A_2, having ped throughout solum; with or without a B horizon.	
Uf6.1-	Coherent soils lacking an A_2, with rough-faced peds and plastic (Uf6) or subplastic	Mainly on shales of Jeeralang,

Northcote classification	Pedologic organisation and soil features	Occurrence
Uf5.1-	sola.	Gunyah and Livingston land systems where the highly clay content has increased the development of pedality and reduced the stripping of sesquioxide coatings resulting in the lack of an A_2 horizon

Minor soils are Uc6.1- and Um7.1- which have dark pedal topsoils with much organic matter. They occur at high elevations or in moist areas such as fern gullies and ravine bottoms.

(iv) Agronomic features and factors affecting processes of deterioration

Profiles examined had no natural hardpans, thus deep rooting would not be inhibited except where high seasonal water tables occur. Fertility levels range from moderate to high, but water-holding capacities in the more sandy soils with low organic matter, are low. The mainly loamy and sandy textures should be associated with good workability. Well-drained alluvial soils are the most suitable for cropping or grazing in the catchments.

Proneness to soil deterioration is highly variable. Soils that are very sandy, weakly coherent or loose, can easily be transported by water. Loamy and clayey soils which are wet for long periods are prone to compaction.

Table 4.2 – Most common uniform soils of Holocene sediment and poorly drained areas of Pleistocene terraces

Northcote classification	Pedologic organisation and soil features	Occurrence
Um5.52 Um6.21 Uc5.21 Uc5.23 Uf6.11	Coherent soils with weak horizonation and weak textural and colour differentiation; A2 horizons absent, earthy fabric (Uc5.2 and Um5.5) or clearly defined structural B (Um6.2) or solum with rough-faced peds and plastic (Uf6.1).	Distributed throughout alluvial and lacustrine deposits.
Uc1.23 Uc1.21 Uc1.44 Um1.44	Non-or weakly coherent (Uc1.2) or coherent (Uc1.4 and Um1.4), but showing little, if any, pedologic organisation except some organic matter accumulation in the surface; non-calcareous; yellow, brown and dark colours	Distributed throughout on the most recent alluvial and lacustrine deposits.

Soils with a moderate degree of pedoligic organisation – the gradational soils

In addition to texture differentiation, soils with gradational profiles have usually developed earthy fabric, pedality and colour differentiation. A_2 horizons may be present.

Texture differentiation can result from loss of clay from the topsoil by downward translocation or by surface wash or from deposition of sand and silt over clay. Various Australian studies have shown that both mechanisms may occur separately or in combination.

Soils of mountains and hills

(i) Environment

The characteristics of this environment have been discussed previously. In such an environment, biospheric reactions and lateral transport of material are probably the most important mechanisms in texture differentiation. An additional process, however, may be the fusion of clay aggregates into silt- and sand-sized units that can occur with heating during forest fires (Wells *et al* 1979, Humphreys and

Craig 1981). The effect becomes less pronounced with depth. Another possible contributing factor is the greater cementation of clay particles by sesquioxides and organic matter in the upper part of the subsoil associated with its more frequent drying. Both processes would tend to produce coarser particles.

The lack of a quartz sand fraction and abundant sesquioxides tend to limit pedological organization in the red soils characteristic of Tertiary basalt. The absence of pale quartz sand prevents the development of bleached horizons while the abundant sesquioxides stabilize the clay in large aggregates, limiting its translocation. Consequently, although these soils are relatively old and highly weathered, they do not have A_2 horizons and a texture contrast between A and B horizons.

(ii) Appearance and classification

Many of these gradational profiles are very similar in colour, stone or gravel content and, to a lesser extent, depth, to a uniform soils in the same environment.

The soils vary considerably in depth, ranging from 0.5 to 2 m, deeper occurrences being mostly in areas of high moisture availability. They are mostly whole coloured and usually shades or red, brown and yellow, though mottled subsoils may occur where older weathering patterns are inherited or where drainage is impeded. Many of the soils contain rock fragments, especially in the lower horizons, and most are pedal at depth.

A range of soils were recorded; the main ones are listed in Table 4.3

Northcote classification	Pedologic organisation and soil features	Occurrence
Um5.52 Um6.21 Uc5.21 Uc5.23 Uf6.11	Coherent soils with weak horizonation and weak textural and colour differentiation; A2 horizons absent, earthy fabric (Uc5.2 and Um5.5) or clearly defined structural B (Um6.2) or solum with rough-faced peds and plastic (Uf6.1)	Disturbed throughout alluvial and lacustrine deposits.
Uc1.23 Uc1.21 Uc1.44 Um1.44	Non- or weakly coherent (Uc1.2) or coherent (Uc1.4 and Um1.4), but showing little, if any, pedologic organisation except some organic matter accumulation in the surface; non-calcareous; yellow, brown and dark colours.	Disturbed throughout on the most recent alluvial and lacustrine deposits

Great soil groups involved are Krasnozems, Red, Brown and Yellow Earths, Red-yellow and Brown Podzolics, Lithosols, Xanthozems, and occasional Humic Gleys where drainage is poor.

(iii) Chemical and physical analyses

The chemical and physical analyses also show strong affinities with those of the uniform textured profiles in this environment.

Nine profiles were analyses. Base saturation of most soils on sedimentary rocks and granodiorites is usually less than 3% and is accompanied by high acidity. As with the uniform textured soils, higher base saturation (9-40%) occurs on the base-rich shales and sandstones of the Strzeleckis. Similar values (10-30%) were encountered in Krasnozems on basalt.

Organic carbon of the topsoil ranges from about 3 to 12%. Available P is usually low, ranging from 5 to 20 ppm, even basalt. The low values on basalt are probably due to high content of iron oxide which fixes P in an almost insoluble and hence highly unavailable form. Available K has the same range as in the uniform textured soils, but was about twice as high (420 ppm) in a profile on granodiorite which contains potassium feldspar. Values can also be high on basalt and on the shales of the Strzeleckis.

Infiltration capacity tends to be very high and would preclude run-off from normal rainfall events. Permeability varies but is generally high.

(iv) Argonomic features and factors affecting processes of deterioration

Inherent nutrient levels vary according to parent rock while total available water-storage capacity is probably higher than that in the associated uniform textured profiles which tend to be shallower. Present nutrient levels appear to be adequate for commercial forestry, especially when based on indigenous species, even though the soils are well leached. As with uniform soils, nutrient decline resulting from forestry in the long term needs to be assessed. Pasture productivity tends to be low and could be increased only with considerable inputs.

As for the uniform soils, the proneness of these soils to water erosion depends on characteristics such as soil permeability and water-holding capacity. The deeper soils, especially if they rest on slowly permeable clay or rock, are prone to landslips. Little nutrient loss by leaching is likely to occur as the soils are already strongly leached and able to retain the remaining nutrients due to their relatively high CEC. Soils with high levels or organic matter and fine textures are prone to compaction, particularly when wet.

Older soils of Holocene sediments

(i) Environment

The deposits on which these soils occur tend to be finely textured and to have shallow water tables. Consequently subsoils remain moist though the upper layers dry out seasonally. Shrinking and swelling associated with this condition is believed to promote pedality of B horizons through the formation of fractures. Also continually moist subsoils stimulate vegetative growth and hence the cycling of bases and the production of organic matter which promotes a strong crumb structure in the topsoils.

Variation in moisture regime between topsoils and subsoils may also promote the development of gradational profiles. Fluctuating water tables and varying degrees of water-logging lead to alternate reduction/oxidation of iron oxides. During reduction the iron becomes more soluble and cam migrate through the soil with moving water; some upward migration with capillary flow to a drier surface seems likely. Here the iron may be re-oxidised and precipitated around small clusters of clay and silt, cementing them into larger units. Humified organic matter can also create such larger units by binding particles. Consequently field textures show a coarsening towards the surface. This may not be reflected in particle-size analyses because sample pretreatment is aimed in removing the binding materials.

In these environments it is also not unusual for gradational profiles to have developed by incorporation of coarse textured sediments into finer textured material.

(ii) Appearance and classification

Topsoils are black or very dark grey and, although rich in humus, tend to have weaker structure than the gradational soils of the mountains. They are coherent and firm to friable when moist and may be mottled with rusty rootlines. Subsoils are usually strongly mottled with shades of grey, greyish brown or dark grey as the dominant colours. Profiles are normally devoid of gravel, apart from occasional small quantities of iron or manganese oxide concretions. Most B horizons have well-developed smooth or rough-faced peds.

A great range of principal profile forms was recorded due to differences in colour, mottling and subsoil pH. The most common classes *sensu* Northcote (1979) are tabulated below (Table 4.4)

Table 4.4 – Most common gradational soils of Holocene sediments

Northcote classification	Pedologic organisation and soil features	Occurrence
Gn4.5- Gn3.9- Gn3.4- Gn3.5- Gn2.8-	Coherent, mostly smooth-ped (Gn3) sometimes rough-ped (Gn4) or apedal but porous earthy (Gn2) B horizons; A_2 horizons are absent or, if present, are not bleached. Very pale brown to light yellowish brown, grey brown and grey matrix colours for Gn4.5, gn3.9, and Gn2.8. Dark grey and dark greyish brown matrix for Gn3.4 and dark brown to yellow brown matrix colour for Gn2.8. B horizon mottling almost universal	Gn3.5 soils probably in relatively better drained sites; relationships of other soil classes to site conditions not worked out.

The universal lack of A_2 developed points to moderate youthfulness while colour, mottles and pedality indicate an environment of seasonal water-logging and drying. In genetically oriented soil group terms, the waterlogged soils with mottles throughout the profile and specifically with rusty-root-line mottling in the topsoil are Humic gleys while those without mottles in the topsoil are Wiesenboden.

A small number of whole coloured gradational profiles were recorded on well-drained alluvial terraces or fans.

(iii) Chemical and physical analyses

Base saturation is similar to that in the uniform soils of lake margins and youngest river terraces inputs of bases tending to offset losses by leaching. Base saturation in the topsoils of the 6 analysed profiles ranges from 25 to 50% and generally increased in the subsoil, sometimes reaching 100%.

In topsoils, Ca and Mg are usually the co-dominant exchangeable ions, with K and Na making up minor and trace proportions respectively. In poorly drained soils, however, the proportion of Na can be higher. Soil reaction tends to be less acidic than in the gradational soils of mountains and hills.

In deep subsoils, exchangeable Na and Mg increase, sometimes dramatically, at the expense of exchangeable H (Exchange acidity) and/or Ca and K. this apparently reflects the presence of somewhat saline groundwater. When base saturation exceeds approximately 70% and the concentrations of Na and Mg are high compared with Ca, the pH is strongly or very strongly alkaline.

The nutrient status in terms of available P and K is also similar to that of the uniformly-textured alluvial soils. Available P ranged from 20 to 65 ppm in most topsoils and decreased to between 1 and 6 ppm in the subsoils. Available K varied from 200 to 760 ppm in topsoils and from 60 to 280 ppm in subsoils.

High organic matter content, good crumb structure and deep topsoils indicate high water-holding capacities and moderate to low bearing strengths at the surface. Permeability appears to be moderate to high in the topsoil, declining with depth.

(iv) Agronomic features and factors affecting processes of deterioration

Measured available P and K levels in the topsoil are considered to be high and moderate to high respectively. Thus fertility levels are high. All 6 sampled soil profiles were situated in pastures which are likely to have been fertilized. The high available P levels could in part be due to added superphosphate. There are no inherent barriers to root penetration, except in areas with shallow seasonal water tables where roots can be restricted to the upper layers. Such soils require artificial drainage to meet their full potential.

The risk of compaction is often high due to loamy or clayey surface textures, high organic matter contents and frequently impeded drainage. Flooding may result in deposition of large volumes of sediments. Gully and tunnel erosion may be a problem where subsoils are sodic and thus dispersible.

The soils are not prone to leaching of nutrients due to factors such as texture and cycling of nutrients by vegetation from shallow groundwater.

Soils with high degree of pedologic organisation – duplex soils

These locality widespread soils are discussed here according to the three main environments in which they occur:

(i) gentle to moderately steep hillslopes receiving high rainfall;
(ii) gentle to moderately steep hillslopes receiving lower rainfall;
(iii) Alluvial plains and gently sloping colluvial aprons

The mechanism involved in texture differentiation are generally the same as those operating in gradation profiles. Chittleborough *et al* (1984 a, b, and c) found the downward translocation of fine clay to be the dominant mechanism on some flood plains and terraces and is probably the usual case on similar landforms in Gippsland. In these situations that texture contrast has developed over a long period during which there has been minimal mechanical disruption. On hillslopes, however, the A horizon probably more commonly represents younger soil creep and/or wash not genetically related to the B horizon (Bishop *et al.* 1980). On slopes developed on the Tertiary fans, inheritance of texture contrast from sedimentary layering is al alternate explanation.

In situations with seasonal anaerobic water-logging, a further process, ferrolysis (Brinkman 1970), can be involved in texture differentiation. Oxidation of the ferrous iron produced during anaerobic conditions, releases H ions which destroy clay minerals. Clay destruction occurs in the topsoil and at the top of the subsoil and consequently results in a progressive deepening of the A horizon as the highly resistant quartz and amorphous silica become more concentrated.

Soils on gentle to moderately steep hillslopes receiving higher rainfall – leached acid duplex soils

(i) Environment

The high rainfall tends to promote leaching which removes bases and increases acidity. This simple relationship, however, does not always hold because soil reaction result from a complex set of processes and inherited properties. For example, on rocks such as granodiorite, which yield appreciable quantities of base on weathering, the soil reaction may be only slightly acidic or neutral. Such a situation occurs near Dargo but here rainfall is only moderate and soils may be subject to less intensive percolation of water. However, slightly acidic soils were also partly basaltic parent materials.

Some duplex soils, particularly in the most strongly leaching environments, do not have a very strong texture contrast between A and B horizons although the colour contrast is marked. The explanation may be that the progressive destruction of clay in the top of the B horizon by high acidity results in a more gradual texture change.

(ii) Appearance and classification

Most soils have a dark A_1 horizon which is generally 10 cm or less thick and a paler A_2 horizon which can very in thickness from 100 cm to less than 5 cm, although 20 to 40 cm is more common. This horizon is not usually pale enough to be considered conspicuously bleached except where subsoils are yellow. Textures of both A_1 and A_2 range from sand to clay loam and most set hard.

Subsoil textures usually vary from sandy clay to heavy clay. Yellow brown mottled colours are the most common but subsoils may be brown or reddish brown, in which case they tend to be whole coloured. Subsoils are usually pedal with fine or medium blocky or granular structure.

Rock fragments may occur in a and B horizons. On unconsolidated Tertiary deposits, rounded quartz or quartzite gravels and/or ferruginous concretions may be found.

The more common principal profile forms recorded are:

Dy3.21 which has a non-bleached A_2 and mottled B; and Dy3.41 which has a conspicuously bleached A_2 and mottled B;

Other common profiles are:

Dy2.41, Dy2.21, Dy3.61, Dy5.21 and Dr2.21.

The soils can be classified as Grey-brown, Yellow, red or Brown Podzolics and Soloths, depending on colour of the B and A_2 horizons and the sharpness of their interface.

(iii) Chemical and physical analyses

In the profiles analysed base saturation in the topsoil generally appears to be higher, 4 to 30%, than in the highly leached uniform and gradational soils of the mountains (3% or less). On granodiorite, base saturations as high as 35 to 60% and dominated by Ca, were recorded. The latter are comparable with those of the young alluvial soils.

Subsoil exchangeable bases tend to be dominated by Mg and Na in the most weathered soils on Tertiary sedimentary parent materials. By contrast, subsoils on granodiorite in Dargo land system were dominated by Ca.

Available P (5-20 ppm) and K (5-280 ppm) are of the same order as in uniform and gradation soils of the mountains, but 3 to 4 times less than in the young alluvial soils. More sampling and analyses, however, could reveal greater variability in nutrients according to parent material.

One yellow soil on siltstones and mudstones (profile 53) was found to have extremely low levels of nutrients (available P 1 ppm and 2-4 ppm available K in the upper 30 cm). Total P levels suggest that the lower profile is similarly low in available P. Base saturation is also quite low, less than 5% in the A horizon, and less than 14% in the B horizon with Ca and K each being 1% or less to a depth of at least 1.2 m. In contrast to the forests found in adjacent areas, the vegetation consisted of health open woodland of *E. consideniana* of strikingly poor form and height.

Although no measurements were made of infiltration rates, lack of structure in the A horizon and its tendency to set hard suggest that it is probably low to moderate. Water-holding capacities are probably low, although they will vary with texture and organic matter level, particularly in A horizons.

(iv) Argonomic features and factors affecting processes of deterioration

The soils appear to have low to moderate fertility with a greater supply of nutrients on igneous parent materials. Water availability is limited by the dense clay G horizons and frequently used for low intensity timber production.

Pasture productivity is affected by these nutrient and water limitations, and possibly by trace element deficiencies. The low levels exchangeable Ca in most situations indicates that the use of superphosphate would promote acidification and nutrient imbalances.

Low to moderate infiltration rates when moist and the tendency of surfaces to be hydrophobic when dry promote run-off. The organic matter in sandy topsoils easily separates from the sand grains as can often be observed where there has been recent surface wash. Sandy A horizons with such weak bonding by organic matter are particularly erodible.

High exchangeable Mg and Na values coupled with low salt contents in subsoils may often promote dispersion of clay and hence tunneling and gullying. However, low pH values in some soils may encourage flocculation of clay by increasing levels of exchangeable A1.

Soils on gentle to moderately steep hillslopes receiving lower rainfall – neutral to alkaline duplex soils

(i) Environment

Reduced leaching associated with lower rainfall tends to produce subsoils with higher contents of exchangeable Ca, Mg, K and Na and thus with higher pH. However, this tendency is modified by variable contents of bases in the parent materials.

Seasonal shrink-swell upon drying and wetting produces a network of cracks. These are also produced by biological disruption and by other mechanical stresses. The cracks ultimately become ped faces through processes of pedologic organisation.

Only 12 neutral to alkaline duplex soils were recorded on hillslopes and these were confirmed to Avon, Westbury 1 and 2, Anderson 1 and 2, Timbarra and Salt Creek land systems.

(ii) Appearance and classification

A horizons set hard A2 horizons are generally present and these may or may not be conspicuously bleached. B horizons tend to be yellowish brown with grey, brown and sometimes yellowish red or brown mottles. Profiles on bedrock often contain stone fragments, while those on unconsolidated Tertiary deposits often include quartz gravels.

Dy3.42 (soils with conspicuously bleach A2) and Dy3.22 (soils with non-bleached A2) were the most common. Others were Dy2.22, Dy2.23, Dy3.43, Dd1.23 and Db2.13. The Db2.13 soil, found on small exposure can be regarded as a Red-brown Earth. The others can be classified as Solodic Soils and as intergrades between Yellow Podzolics Solodics.

(iii) Chemical and physical analyses

One profile, a Solodic Soil (Dy2.33), was sampled for analysis. The topsoil is dominated by exchangeable Ca (30-35%) while the subsoil is dominated by exchangeable Mg (45-58%) and Na (14-20%).

In terms of available P and K, this soil is very similar to the other analysed duplex soils.

(iv) Agronomic features and factors affecting processes of deterioration

Soil fertility appears very similar to that in the duplex soils discussed above, both from the point view of commercial forestry and of pastures. Lower rainfall contributes an additional limitation.

Subsoils probably have very low permeability associated with high dispersibility. Topsoils appear to have low to moderate water-holding capacities and low infiltration rates. Infiltration rates are probably less than rainfall rates during intense storms and low permeability of subsoils would also reduce the amount of water entering the soil. Both features promote run-off water erosion.

Soils of plains and gently sloping colluvial aprons.

(i) Environment

Terrain is level or very gently inclined. Many areas receive seepage which may bring in leached salts from adjacent slopes, or are influenced by high regional ground water tables. In addition profile permeability is often low. Consequently seasonal water-logging is widespread. Nature and amounts of salts vary from locality to locality as a result of variability in salt loss due to drainage and in salt inputs in incoming seepage.

Salts are likely to have played a role in soil formation through their effect on the physical properties of clays. High exchangeable Na and Mg percentages in combination with low salt concentrations tend to increase dispersiveness and shrink-swell capacity and to decrease permeability while high exchangeable Ca promotes flocculation and increases permeability. The processes affect soil fabric, soil moisture regime and the ability of plant roots to penetrate and persist in deeper soil layers.

The very wide range of subsoil pH from strongly acid to strongly alkaline, which is common throughout this environment, is probably due to such variable seepage and groundwater influences.

(ii) Appearance and classification

As is usual with duplex soils, the thickness of A_1 and A_2 horizons varies greatly. The A_1 horizon tends to be thicker, often up to 35 cm, on the younger alluvial land forms. This is doubtlessly a function of biological activity and hence of nutrient levels and water supply. On the older, generally less fertile materials, A_1 horizons are less than 10 cm thick. Most soils have an A_2 horizon which may or may not be bleached and which is commonly mottled. Conspicuous bleaching is probably associated with more severe seasonal water-logging. The combined thickness of A_1 and A_2 horizons is usually 30 to 60 cm, but occasionally as much as 100 cm. Most A horizons are hard setting.

B horizons are mostly pedal and mottled. In road cuttings and pits, some were noted to be columnar with a blocky substructure but the columnar structure was not detected when augering. Most B horizons are yellowish brown or greyish brown and reddish brown subsoils also occur. Red soils occur mainly in Briagolong, Walnut and Maffra 1 land systems. Soils on Tertiary or Pleistocene alluvial deposits may contain rounded quartz gravels. Ferruginous nodules may also occur, but usually in small quantities.

Gilgaied surfaces were observed in places, although the subsoil clays do not appear to be strongly cracking.

The most common principal profile forms are: Dy3.21, Dy3.22, Dy3.23, dy3.41, Dy3.42 and Dy3.43. all these have hardsetting A horizons and yellowish brown mottled and pedal B horizon, but they differ in having an unbleached A2 (Dy3.2) or conspicuously bleached A2 (Dy3.4) and in subsoil pH which may be acid, neutral or alkaline. Dy5, Dd2 and Dr2 profiles were less common.

The main soil groups involved are Yellow Podzolic soils and Soloths (acidic, yellowish brown B horizon) and Solodic Soils (neutral-alkaline yellowish brown B horizon with blocky structure). Less common are Red and Brown Podzolic Soils (acidic, red or brown B horizon), Solodized Solonetz (acidic, columnar B horizon), Red-brown Earths (neutral to alkaline, reddish brown B horizon, rich in Ca), Gleyed Podzolic Soils, Humic Gleys and Wiesenboden (strongly hydromorphic)

(iii) Chemical and physical analyses

As with the neutral and alkaline duplex soils of hillslopes, most of these soils are characterised by high proportions of exchangeable Na and Mg in the lower B and C horizons. However, the younger alluvial materials in Briagolong and Walnut land systems appear to be Ca dominated. Base saturation seems to vary somewhat independently of subsoil pH, except that low pH is usually associated with low base saturation. The pH ranges from 4.5 to 9.0.

Nutrient levels are similar to those in other duplex soils. Available P and K in topsoils usually range from 5 to 25 ppm and from 50 to 300 ppm respectively. Low available P values occur on the older terraces (Redgum 1 and Redgum 2 land systems). The lowest values occurred on a site supporting *E. cephalocarpa*, a species thought to indicate very low fertility, possible coupled with poor drainage.

Subsoil permeability and surface infiltration are usually low.

(iv) Agronomic features and factors affecting processes of deterioration

Soils which have thick A1 horizons, thin loamy unbleached and unmottled A2 horizons and slightly acid to neutral, finely structured and well drained B horizons, have moderate to high productive potential.

Soils with thin A1 horizons, deep sandy bleached a2 horizons and very acid or alkaline B horizons with a predominance of grey and pale brown colours, have low productivity.

Available P and K rate from low to high soils sampled from both pastures and open forests and there is no obvious relationship with previous fertilizer use, if any. Nutrient levels, however, are only one aspect of soil productivity and must be considered together with moisture regime and rooting potential.

Water logging and associated compaction are widespread. Run-off and gullying are promoted by low surface infiltration and by dispersible subsoils.

Soils with a high degree of pedologic organisation - uniform sand soils

Sands of old dunes, sand sheets and outwash fans

(i) Environment

Sands with a high degree of pedologic organisation occur on old dunes, sand sheets and sandy outwash fans in areas of moderately high rainfall. Characteristic locations are the inner barrier, the sand deposits that occur on the Pleistocene terraces, for example, those of the old barrier system mapped in Barrier and Perry land systems, and hillslopes formed in the Tertiary fans adjacent to the uplands. These sands consist almost entirely of inert quartz although there are small quantities of minerals which could release iron and other elements during weathering.

The sands are stabilised by vegetation which tolerates very low levels of nutrients and moisture. Rapid drainage and low water-holding capacity result in deep root systems of perennial plants and tree throw is rare. Biological activity is minimal because of low nutrient levels, droughtiness and acidity. Consequently there is little biological mixing of materials.

Atmospheric dust and rainfall contribute to the pool of nutrients. However, high permeability and low CEC promote leaching. The pH values are very low, particularly in topsoils where the higher CEC due to organic matter allow H ion accumulation. High acidity and permeability promote the stripping and leaching of iron, aluminium and humus compounds from the A horizons. These are precipitated at depth to form B_h (precipitated humus) and B_{ir} (precipitated iron and aluminium) horizons. The B_{ir} horizon usually forms below the B_h.

(ii) Appearance and classification

Morphological variation is related to factors such as soil age, intensity of leaching and parent material composition.

A_1 horizons are black to very dark grey and generally 0.1 to 0.2 m thick. They are mostly porous and apedal grains. The paler A2 horizon is conspicuously bleached in about half the recorded profiles, apedal, loose and usually 0.3 to 1.0 m thick.

B_{ir} and B_h horizons are developed to varying degrees. They may occur singly or in combination. There is evidence from podzol chronosequences at Cooloola in Queensland that the depth to B horizons in sands increases with increasing age of soil (Thompson 1981; Seymour 1982).

Mostly the accumulation of humus and iron oxide are sufficient to form coffee rock, but in some sandy soils the grains have been coated only thinly and subsoils remain weakly coherent. The hardpan is often earthy, with an irregular or regularly wavy surface. It can also appear as a zone of hard nodules. The B_h horizon is usually less than 0.15 m thick, but the B_{ir} can be diffuse and up to 0.5 m thick. The sands of the C horizon are usually light brownish yellow.

The commonly recorded principal profile forms are given in Table 4.5.

These soils are classified as Podzols. Terms such as iron podzol, humus podzol and humus-iron podzol are also used to indicate the presence of a B_{ir}, and B_h or both. The least developed profiles with barely established, non-coherent B_{ir} horizons may be termed Siliceous Sands.

Table 4.5 Common soils of old dunes, sand sheets and outwash fans

Northcote classification	Pedologic organization and soil features
Uc4.31 Uc4.32	Cemented B_{ir}, no B_h, non-bleached A2
Uc2.31 Uc2.32	Cemented B_{ir}, no B_h, conspicuously bleached A_2
Uc2.36	Cemented B_{ir}, B_h, bleached A2
Uc2.21	Weakly coherent B_{ir}, bleached A2
Uc4.22	Weakly coherent B_{ir}, no B_h, non-bleached A_2

Some polygenetic profiles were noted. For example, a Podzol may have been truncated and subsequently buried by sand in which a new profile has developed. The older B_{ir} may contain nodular coffee rock while the later B_{ir} may be weakly coherent. Podzol also appear to develop in deep sandy A horizons of duplex soils, with the B_{ir} usually occurring at the transition to the clay horizon.

(iii) Chemical and physical analyses

The most significant chemical property of these soils is the extremely low CEC of the A2 and C horizons. Horizons with higher CEC, such as the A_1, B_h and sometimes the B_{ir}, are usually thin. Despite their low CEC, base saturation often ranges between 10 and 40% and is usually much higher than in the uniform and gradational soils of the mountains. This may be associated with lower rainfall and hence less leaching on the coastal plains, through this would be offset to some extent by the lower water-holding capacities which would result in a greater proportion of rainfall passing through the profile. Perhaps the native vegetation of Podzols is more effective in cycling nutrients, thus maintaining higher base saturation. However, the quantities of bases in the root zone are very low.

Available P and K in topsoils are low with values ranging from 2 to 7 ppm and 10 to 70 ppm respectively, decreasing to 1 to 2 ppm and t to 10 ppm respectively in subsoils. B_h and B_{ir} horizons commonly have P and K levels similar to those in the topsoil.

Outstanding physical characteristics are high permeability, low water-holding capacity and the lack of cohesion between sand grains. Unless there is a high water table, drainage is excellent to excessive. The available water capacity is about 5 to 10 %, depending on the quantity of organic matter, and water is soon exhausted by plants with the onset of dry periods.

(iv) Agronomic features and factors affecting processes of deterioration

Nutrient levels, pH and available water content are very low. Trace element deficiencies are probably widespread. Consequently low productivity can be expected. Correcting the nutrient and pH deficiencies with fertilizers would not overcome the very low water-holding capacity. Moreover, added nutrients would be rapidly leached out. Thus in terms of commercial forestry, pastures or cropping, these soils have low value.

Sands are very susceptible to leaching of nutrients and wind erosion. Oxidation of organic matter, which can be accelerated by cultivation and by use of fertilizers, will tend to increase erodibility by reducing cohesion. In addition oxidation or organic matter would reduce CEC and thus increase leaching.

The low degree of bonding between organic matter and the sand grains can lead to their rapid separation and transport by fast flowing run-off water. Such erosion is limited on deep sands by infiltration capacities but there is evidence that significant movement occurs when surfaces are seasonally hydrophobic.

5. NATIVE VEGETATION

Introduction

Indigenous vegetation is a resource with many commercial, functional and aesthetic values. It provides timber, pollen and nectar for honey production, and feed for livestock. Not so well recognized are its functions in water supply, the control of erosion and the provision of habitat for native animals. The importance of vegetation for water catchment and prevention of erosion are specific examples of the general value of indigenous vegetation that relate to its being an integral part of the land, inextricably associated with many of the land's processes, particularly hydrological processes. Aesthetic values of native vegetation are based on it's intrinsic nature. There is increasing awareness of the very real but rather intangible needs of people for wilderness and natural landscapes – native vegetation is an essential component of these.

The quality of vegetation and soil interdependent. Consequently it is necessary that both are utilized and managed so that neither resource deteriorates and the long-term productivity of each is sustained or enhanced.

To maintain the native vegetation and productivity of the soil in the long-term, it is necessary that their management be based on a sound understanding of the processes occurring. Too often the environment is viewed at one point in time, or, at best, within a very limited time span. Such limitations to our perspective are often the result of immediate economic considerations and community needs but they also seem to be the result of an inability on the part of most individuals to acknowledge and comprehend time scales beyond that of their lifetime. A major consequence of this limitation in perspective is that the environment tends to be regarded as static and, although there may some awareness of the processes occurring, the changes in these with time, and/or their future consequences, are not recognised.

Also required for maintenance of long-term productivity is recognition of the integrated functioning of vegetation and other land resources. There has been a tendency for each resource to be viewed and managed separately but integration requires that their management be co-ordinated and based on an understanding of the processes responsible for their inter-related functioning.

Within the catchment of the Lakes there is a large diversity of land types, each with its own vegetation communities and range of processes. As well as this inherent diversity, there is a variety of man-made modifications to the land, particularly to the vegetation. The vegetation now ranges from relatively natural native forests, woodlands, heaths and grasslands through managed native forests to highly modified and managed vegetation types including pastures, crops and exotic timber plantations.

Not only is the land diverse but there are often a number of functions and possible uses for an areas. This leads to conflict within the community over how areas should be used and managed. As a consequence of this natural diversity and multiplicity of possible uses within the region, and understanding of the land and vegetation is both essential and complex.

Other chapters have provided information on the characteristics and processes associated with the climate, geology, landform and soil; it is the aim in this chapter to describe the native vegetation and Its distribution in relation to the other land features, and to provide an understanding of some of the processes occurring within it, particularly those which integrate it with the land.

Previous Botanical Investigations

Botanical work within the Gippsland Lakes catchment as initially taxonomic and was carried out either for scientific reasons or as an inventory of useful timber resources. Scientific enquiry, the value of the timber resources and, more recently, an awareness of the need to conserve natural areas have all been factors stimulating further research both within the catchment and in similar areas outside it, so that there now exists much botanical information.

Baron von Mueller, one of the earliest explorers in the high country, made extensive botanical collections during his trips of 1852 and 1854 which included parts of the Avon, Mitchell, Wentworth and Dargo River catchments, Mount Wellington, the area near Mount Hotham and the Gippsland plains between Lake King and Melbourne. Details of these trips and the plants collected are given in his 1st, 2nd and 3rd Annual Reports. He also visited Mount Baw Baw and Mount Mueller in 1860 and the headwaters of the Macalister River in 1861.

At the turn of the century, numerous smaller trips to the alps began, and these would have included visits to the Gippsland Lakes catchments near Mount Hotham. Details of many species collected are recorded in the Victorian Naturalist, for example by Walter (1899), Maiden (1900), Barnard and Sutton (1903), Theile (1905), Sutton (1905), Ewart (1910), and Tadgell (1922).

Hart (1923) recorded plants in the region around Bairnsdale. More recent species lists and community descriptions covering specific areas within the catchment are found in Costin (1957), Rowe and Downes (1960), Tanjil River Environment study Group (1973), Sibley (1975), Parsons *et al* (1975), Beauglehole *et al* (1975), Melbourne and Metropolitan Board of Works (1975), Scarlet (1975), Ladd *et al* (1976), Chesterfield (1978), Parr-smith (1978), Beauglehole (1981) and Gullan and Norris (1981). Corrick and Norman (1980) give a brief description of the wetland communities.

Reports of the Land Conservation Council (1972, 1975, 1977, 1980, 1982) give general description and maps of the vegetation on public land. The Forests of Commission, now included in the Department of Conservation, Forests and Lands, has unpublished maps of the dominant eucalyptus for parts of the high country and for very limited areas in the lowlands.

The most recent vegetation survey is that by Gullan *et al* (1981) which covers the whole of the Gippsland Lakes catchments. They have recognized 13 communities, which usually contain several components, on the basis of floristic composition.

Description of the Native Vegetation

Terminology

Structure

The structure of the vegetation has been described using the classification for Specht (1970) except for the height classes of the tree stratum. For this stratum the following height classes have been used:

8-15 m	Class I
15-28 m	Class II
28-40 m	Class III
>40m	Class IV

Nomenclature

Species names are those given in Willis (1970, 1972) with amendments according to Forbes *et al* (1984). Naturalised alien groups (family, genus or species) are prefixed by an asterisk, after Willis (op. cit)

E. dalrympleana – E. rubida: because of the close similarities in morphological features between these two species, it has not been practicable in the present study to separate the two. For this reason the approach adopted by Rowe (1967) of grouping both species under the name *E. rubida* has been followed. It should be noted, however, that *E. dalrympleana* appears to largely replace *E. rubida* at higher elevations, probably above 1100 m, and seems to be uncommon below 750 m.

E. camaldulensis – E. tereticornis: as these species are also difficult to distinguish from each other (Willis 1972), they have been grouped as *E. tereticornis* in this report. To the east of Sale *E. tereticornis* is generally dominant, but the La Trobe Valley both species occur. Willis records the presence of ‘intermediate states’.

General

The present distribution of the native vegetation is determined by past distributions, present environmental conditions and the attributes of the different species.

The main environmental factors affecting the broad distribution of the vegetation are moisture, temperature, light and availability of nutrients and these are determined by climate, geology, topography and soil. It is not only the mean or annul values of the different climatic parameters which are important, but also their daily or seasonal occurrences, ranges and variability (Williams 1955).

Within the extensive catchment of the Gippsland Lakes, there is a great diversity in those factors. The more important climatic influences appear to be the cooler and moister conditions with increasing elevation in the East Victorian Uplands and in the South Victorian Uplands, the drier conditions in rain-shadow areas and the milder temperatures near the coast. Variations in soil depth, drainage, water holding capacity and fertility have local effects within these climatic regions.

The most common structural form is open forest with height classes II and III being the most widespread. In addition to open forest, extensive areas of woodland, open woodland, closed scrub, sedgeland and herbfield occur. There are also a few patches of closed forest, shrubland, grassland, bog and other communities.

The tallest trees of most of the open forests and woodlands are eucalyptus. Moulds (1965) claimed that there is a tendency for one eucalypt to be dominant where tree growth is significantly limited by low temperatures or by a marked deficiency or excess of moisture, but where temperature and moisture are less limiting, there is usually a number of eucalypt species. This is generally true within the study area though a major exception is forests dominated solely by *E. regnana* where neither temperature nor moisture are limiting.

The eucalyptus and their general distribution

Twenty-three eucalyptus are common and widespread. Eight such species occur at elevations below approximately 600 m. Of these, *E. tereticornis* grows on the central and eastern plains, where soil moisture is usually deficient in summer and often excessive in winter or spring, and greatly outnumbers the few additional species which occur with it. *E. Ovata* is often the sole dominant in poorly drained areas and *E. nitida* and/or *E. viminalis* var. *racemosa* sands. *E. polyanthemos* may occur to a limited extent in the above communities, but are common in the mixed species forests of the foothills.

Eleven of the 23 species grow mostly in mixed species forests over a wider elevation range. These are *E. sieberi*, and sometimes the only tree species on ridge tops; *E. radiata; E. rubida;* on drier sites *E. dives*, *E.goniocalyx*, *E. macrorhyncha* and *E. mannifera;* and usually on moister sites *E. cypellocarpa*, *E. oblique*, *E. viminalis* and *E. globulus.*

The remaining four species occur in wetter localities and/or at higher elevation. *E. regnans* or, above about 100m, *E. delegatensis* form single species forests which usually replace the mixed species forests where annual rainfall exceeds about 100 mm. Above about 1500m, *E. pauciflora* predominates often joined by *E. rubida* except towards the tree line. *E. stellulata* is also common at higher elevations, replacing both *E. rubida* and *E. pauciflora* poorly drained and/or frost prone sites.

Another 17 eucalyptus are less widespread. Of these, 11 are seldom found above 600 m elevation and include *E. cephalocarpa; E. melliodora*, mainly on alluvium; and in mixed species forests, *E. baxteri*, *E. muellerana* and *E.*

Native Vegetation associated with the Broad Land Types

The present native vegetation recorded in the different land types may be modified from that which existed prior to European settlement; change in the structure and composition of the understorey is particularly likely. Changes known to have occurred are referred to.

The vegetation units described have been subjectively recognized, that is, they were not determined by numerical analysis of the data, and have been delineated on the basis of major variation in structure and/or species composition of the upper stratum. They are similar in concept to the associations of

Beadle and Costin (1952) except that no regard has been given to seral stage and the units are often broader.

A more detailed subdivision of some of the vegetation units on the basis of structure and composition of the dominant stratum is given, along with a map of the distribution, in the LCC reports (1980, 1982). A more common comprehensive classification of the native vegetation of the catchment has been done by Gullan *et al* (1981) who delineated communities on the basis of total species composition using numerical techniques. Some of the regional reports listed previously also provide more detailed species information.

The discussion in this section gives only the predominant species of the upper stratum of each unit; Table 5.1 gives some of the commonly associated species.

Vegetation of the Uplands – the hills mountains underlain mostly by consolidated rock.

The vegetation within the sub-alpine and alpine tract seems to be influenced mostly by temperature and exposure while below the sub-alpine zone, soil moisture availability is probably the most important factor. Soil moisture availability is influenced not only be rainfall but also by soil texture, structure, depth and stoniness; aspect, which influences the daily temperature regime and exposure to wind and hence evapotranspiration; and slope, which influences the extent of run-off. Further investigation is needed to quantify the correlation between soil moisture availability and vegetation communities.

Alpine and sub-alpine

Baw Baw, Bennison, Hotham, Moroka, Nunniong and Reynard land systems.

Areas with alpine and sub-alpine climates have been identified by their rather distinctive vegetation types even though boundaries so recognized tend to be diffuse and the factors difficult to define. Sub-alpine terrain is definitely here as that with woodlands and forests in which *E. pauciflora* is the predominant eucalypt, or with the associated treeless communities such as the bogs. The much less widespread alpine zone is defined as the area above the tree line. These definitions differ slightly from those of Costin (1957) and Costin *Et al* (1979) which include reference to climatic factors.

Costin considered the sub-alpine conditions do not occur in Victoria below approximately 1370 m, but using vegetative criteria, the sub-alpine zone extends to as low as 1000 m in some areas.

The climate is unfavourable for plant growth, mean monthly temperatures not exceeding 0°C for at least 6 months of the year. In addition, a large range of ambient conditions often occur on a daily, seasonal and annual basis. Warm days can be followed by freezing nights with a diurnal temperature range as great as 28 C and severe frosts can occur throughout the year. Desiccating winds are common, and their effects are particularly severe on northern and western aspects.

Vegetation can be seen to vary with the degree of exposure to extremes of temperature and wind and with soil moisture, aeration and depth. The sub-alpine tract carries mainly shrubby or grassy woodland I or II, less commonly open forest I or II. In places these have been temporarily replaced by dense regrowth scrub as a result of fires. There is also tussock grassland, open heath, sedgeland, mossland and closed forest.

In a few alpine areas, the vegetation is composed of herbfield, grassland, feldmark and heathland, sedgeland and mossland similar to that of the sub-alpine zone.

(i) Closed Forest

Closed forest of *Nothofagus cunninhamii* was not observed during this survey in the sub-alpine zone but it has been recorded there (Melbourne Metropolitan Board of Works 1975, Howard and Ashton 1973) as closed forest I or II, mostly in gullies and near bogs, often in association with *Leptospermum grandifolium*.

(ii) Woodland I and II, open forest I and II

E. pauciflora is the dominant eucalypt and forma pure stands mainly as woodland I at higher elevations. At lower elevations, or on less exposed sited, woodland II, grading to open forest I and II, is more common and *E. rubida* is sometimes present.

Other Eucalyptus of the sub-alpine tract include *E. stellulata*, *E. glaucescens* and *E. kybeanensis* on Mount Useful. *Nothofagus cunninghamii* occurs in some of the sub-alpine woodlands of the Baw Baw Plateau.

The understorey of the woodlands and forests tends to be dominated by tussock grass, *Poa australis* spp. agg. And by *Celmisia asteliifolia* where the soils are deeper. Where the soil is particularly shallow or rocky, or in areas that have been burnt more frequently, grasses and herbs are less common and shrubs predominate (Costin 1957).

On the margins of the treeless cold air drainage valleys, *E. pauciflora* sub-alpine woodland can occur below its usual elevation range (Costin 1961), it may also be replaced, at least in part, by the more frost resistant *E. stellulata* (Farrell and Ashton 1973). In places, cold air drainage creates a temperature inversion in valleys so that the lower valley slopes as well as the higher elevation crests are colder than the midslopes. As a result, sub-alpine woodland grows on lower slopes and crests while them ore sheltered midslopes carry an open forest of *E. delegatensis* (Farrell and Ashton 1973).

(iii) Heathland, sedgeland and mossland

Open heath of Hovea longifolia, Oxylobium alpestre and O. ellipticum usually predominates on more exposed sites which are often steep with shallow, rock soils and with less persistent snow cover. Less commonly, as on Mount Baw Baw, the main species are Pultenaea muelleri, Helichrysum hookeri and Grevillea australis.

In permanently wet localities, a heath dominated by *Epacris paludosa*, *Baeckea gunniana* and *Richea continentis* occurs. This heath intergrades with sedgeland of *Empodisma minus*, *Carex gaudichaudiana* and *C. appressa* and mossland of *Sphagnum* spp.

(iv) Tussock grassland

Tussock grassland dominated by *Poa Australia* spp. agg. Occurs mainly on gentle slopes where soils are relatively deep and moist, often where there is cold air drainage and/or restricted soil aeration.

(v) Herbfield and Feldmark

Herbfield dominated by *Celmisia asteliifolita* and *Poa Australia* spp. agg. Is the predominant vegetation type in alpine area. Where organic loams formerly underlying the herbfield have been eroded to expose stony parent material, notably on Mount Hotham, the bare slopes have been partly colonized by a feldmark of the herb *Ewartia nubigena*.

Terrain below the sub-alpine zone

Avon, Baldhead, Bindi, Birregun, Blomford, Boola, Bulltown Spur, Buln Buln, Carrabungla, Cascade, Clifford, Collins, Dargo, Deadhorse, Delburn, Diabase, Elizabeth, Glenmaggie, Gunyah, Haunted Hills, Jamieson, Jeeralang, Kirchubel, La Trobe, Livingstone, Macalister, MacAdam, Mitchell, Neerim, Stewart, Talbotville, Tambo, Tanjil, Thorpdale, Timbarra, Toorongo, Turton, Walnut, Wellington and Wonnangatta land systems.

Hills and mountains on consolidated rock below the sub-alpine zone occupy a large proportion of the study area. Lithology, physiography and climate are variable and consequently the structure and composition of the vegetation is diverse. Whilst factors such as temperature, soils moisture availability and site drainage account for much of the variation, fire history appears to be significant, particularly in the composition of understoreys.

The predominant structural forms are open forest II, often shrubby, on drier slopes and ridges and open forest II or IV, mostly shrubby or layered, in areas of higher moisture availability, usually protected slopes and gullies at higher elevations.

Nothofagus closed forest occurs in some gullies in the west with higher rainfall while small pockets of close forest with *Acmena smithii*, described by D. Cameron (unpublished data) as ‘warm temperate rainforest’ occur in a few drainage corridors at lower elevations.

Open forest I and woodland I and II are also found, usually on dry slopes with shallow soils though woodlands with a heathy understorey occur in more humid areas on silty soils (Stewart land system)

Other vegetation types include closed scrub of Melaleuca and, in bogs and seepage areas at higher elevations, heathland, sedgeland and mossland.

(i) Closed forest

Nothanfagus cunninghamii was observed on slopes and along drainage lines in the areas of higher rainfall. According to Howard and Ashton (1973) closed forest dominated by N. cunninghammii occurs in southern Victoria in areas with a mean annual rainfall greater than 1500 mm slopes, and 1350 mm in protected gullies.

At elevation between 650 m and 1300 m, the *Nothofagus* closed forest is usually height class II with a tendency to be multi-stemmed whilst below 650 m, mostly in the South Victorian Uplands, height classes are III or IV. The structure was sometimes found to be an open forest woodland but this has been attributed to disturbance of the closed forest (Ashton, personal communication).

In gullies with high rainfall in the east of the East Victorian Uplands, *N. cunninghammii* is replaced by *Atherosperma moschatum*.

The closed forest II with *Acmena smithii* that occurs in isolated patches in drainage corridors at low elevations in the east is quite distinct from the far more complex subtropical rainforest which extends northwards from an area 120 km north of the Victorian border (D. Cameron, unpublished data). According to Cameron, *Acmena smithii* is generally the predominant tree in the Lakes catchment, other dominants include *Acacia melanoxylon; Rapanea howittiana* which grows best on deep, alluvial soils; *Pittosporum undulatum,* sometimes a pioneer species for closed forest because it can tolerate dry conditions; *Tristania laurina,* on stream margins, and *Acronychia oblongifolia* which grows on warmer, more humid sites. Amongst the understorey species are climbers or lianes, several of which occur at each site, herbs, and numerous epiphytes. Epiphytes are plants wholly supported by the stem or leaves of host plants or by rocks and which obtain moisture from their support and from the unusually humid atmosphere under the closed canopy. The epiphytes are mainly ferns, mosses and lichens but also occasionally includes the orchid, *Sacrochilus australis*. The herbs are of two main types, those that are shade tolerant and those which become established following the occurrence of gaps in the tree canopy.

(ii) Open forests and woodlands

The diversity of open forests and woodlands limit this discussion to observed general trends.

(a) Elevations between the sub-alpine zone and approximately 900 m

Exposed sites carry woodland to shrubby open forest I, II with *E. dives*, *E. pauciflora, E. rubida* and occasionally *E. glaucescens* or with *E. dives and E. mannifera*.

Towards the more protected easterly and southerly aspects, on lower slopes and on deeper soils, this shrubby open forest usually gives way initially to a shrubby or layered open forest III or IV of *E. delegatensis, E. dives* and/or *E. rubida,* and ultimately to *E. delegatensis* shrubby or layered open forest III or IV sometimes associated with *E. nitens* and *Nothofagus cunninghamii*, particularly in the wetter western part of the catchment. On steeper slopes these changes can be telescoped so that sub-alpine woodland is abruptly replaced by *E. delegatensis* shrubby open forest. It seems that at least some of the *E. delegatensis* forests which now have shrubby composed understoreys may originally have had understoreys compose mainly of grasses and herbs (Carr and Turner 1959). Such a change could be due to grazing and/or burning.

At these elevations *Leptospermum grandifolium,* sometimes with *Polyscias sambucifolius*, often occurs in drainage areas wither as an open forest I or II or as an understorey species in an open forest dominated by E. radiate and *E. viminalis*.

(b) Elevations below approximately 900 m

With decreasing elevation the *E. delegatensis* open forests tend to be replaced by open forests II and III, often shrubby, of *E. cypellocarpa*, E. oblique and , in the east, *E. globoidea, E. dives, E. radiate, E. rubida*, or, on ridges and crests *E. sieberi*, often associated and occasionally predominant. *E. delegatensis* is restricted to the wettest localities.

At approximately 900 m *E. regnans* tends to replace *E. delegatensis* on the wetter sites in the western part of the East Victorian Uplands. Towards the upper limit of its elevation range, E. regnans is occasionally accompanied by *E. nitens* and, at lower elevations, by *E. oblique and E. cypellocarpa. E. regnans* also occurs in the South Victorian Uplands, often with *E. oblique, E. cypellocarpa and E. globules*. It is not common in the east of the East Victorian Uplands.

The present understorey of the *E. regnans* open forests are usually dense, particularly where mean annual precipitation exceeds 1000 mm. According to Gillepie (1965) the undergrowth in some of these forests was originally more sparse, consisting mainly of a ground layer of ferns with the scrambling grass *Tetrarrhena juncea*. The change from open to dense scrubby understoreys was caused by frequent burning and, according to Reichl (1968), occurred in the very early days of European settlement.

The driest sites, usually on exposed aspects and with shallow soils have, at upper elevations, a similar vegetation to the dry sites above 900 m, with an open forest I and II or woodland II of *E. dives, E. mannifera and E. rubida.* This is generally replaced at lower elevations by an open forest II, though open forest I and woodland I and II also occur, with one or more of *E. macrorhyncha, E. muellerana, E. polyanthemos and E. sieberi* and occasionally *E. consideniana, E. goniocalyx, E. globoidea* and, on granitic genesis rocks around Swifts Creek, *E. albens*.

In the drier limestone areas around Bindi there are remnants of grassy woodland II of *E. pauciflora* and *E. viminalis* and, on exposed upper slopes, *E. pauciflora*. Remnants stands of *E. goniocalyx* sometimes with *E. polyanthemos* occur on the colluvial slopes.

On some of the silty soils in Stewart land system there is a heathy woodland I of *E. consideniana*, often with *E. cephalocarpa*. In this region *E. consideniana* may also occur in open forest II with *E. oblique and E. radiata*.

Pockets of open forest II, dominated by *E. tereticornis*, sometimes with *E. melliodora*, occur on basaltic slopes adjacent to the Gippsland plains and appear to be remnants of a formerly more extensive community.

Below 900 m the predominant eucalypts on most alleviated valley floors and adjacent colluvial slopes are *E. ovata, E. radiate* and *E. viminalis. E. bridgesiana, E. melliodora* and *E. polyanthemos* are common in the east below about 600 m.

(iii) Closed scrub

E. regnans does not bear seed until it is 15-20 years olds, whilst seed storage on the tree is limited to 2 years and seeds in the soil are short-lived (Ashton 1956 and Cunningham 1960, cited by Gill 1975). In addition the tree does not regenerate form lignotubers.

Consequently, burning at intervals less than 15-20 years as well as early uncontrolled logging, has resulted in the demist of numerous *E. regnans* forests, particularly on some western slopes of the East Victorian Uplands, for example near Mount Baw Baw and in the South Victorian Uplands. Frequently these forests have been replaced by scrub dominated with *Acacia obliquinervia* and *A. dealbata*, and infested by the noxious weed blackberry (*Robus* spp). and ragwort (*Senecia jacobaea*).

Closed scrub or sometimes closed forest I also replaces the forests in some areas with poor drainage, but in these situations it is dominated by *Melaleuca ericifolia* or *M. squarrosa*. For example, a closed scrub with *M. squarrosa* is common in the seepage and poorly drained areas characteristic of Stewart land system.

(iv) Open Heath, sedgeland and mossland

Bogs, seepage zones and areas of restricted drainage at higher elevations sometimes have open heath, sedgeland and mossland with species including *Baeckea gunniana, Callistemon sieberi, Epacris paludosa, Empodisma minum* and *Sphagnum cristatum*.

Vegetation of the Lowlands – low hills and plains with unconsolidated material at the surface

Low hills and sloping terrain with mostly duplex soils

Salt Creek and Westbury 2 land systems and parts of Anderson 1 and 2, Clifton, Stockdale and Westbury 1 land systems

The vegetation is mainly open forest II and, less frequently, open forest III both of which are often shrubby. Shrubby woodland II or very small remnants of closed forest II occur occasionally.

(i) Open forests

The open forests are often mixed species forests with predominance variable. In the wetter western region, one or more of *E. bridgesiana, E. consideniana, E. cypellocarpa, E. dives, E. oblique and E. radiate* usually predominate. Associated species include *E. cephalocarpa* in less well-drained areas, and *E. sieberi*.

In the drier eastern regions, the open forests are dominated mainly by *E. globoidea* or, on the upper slopes east of the Tambo River, by *E. sieberi. E. tereticornis* is predominant near the plains. Less common species include *E. bauerana* east of the Tambo River, *E. bosistoana* and *E. botryoides* near the coast, *E. cypellocarpa* on southern aspects, *E. bridgesiana, E. macrorhyncha, E. muellerana, E. polyanthemos, E. radiate* and *E. sideroxylon.*

Composition of the open forest along drainage corridors is also variable. Commonly found species include *E. viminalis, E. ovata, E. bridgesiana, E. cypellocarpa* and *E. radiate, E. melliodora, E. polyanthemos* and *E. globules* sometimes also occur.

(ii) Closed forest

Very small remnants of the *Acmena smithii* closed forest II, with variable species complexity, occur in a few sheltered gullies, mostly in the far east of the catchment.

(iii) Shrubby woodland

A shrubby woodland I dominated by *E. ovata* and/or *E. radiata* grows in some drainage areas.

Low hills and sloping terrain with sandy soils manly on Tertiary deposits

Gormandale land system and parts of Anderson 1 and 2, Clifton, Sandy, Stockdale and Westbury 1 land systems.

Open shrubby or ferny woodland I, II with *E. consideniana, E. nitida, E. viminalis* var. *racemosa* and Banksias errata is typical of parts of Gormandale land system and of the areas of Sandy land system associated with it. The sandy deposits of Anderson 1 and 2, Stockdale, Westbury 1 and the reminder of Gormandale, however, have open forest II, III with E. oblique usually predominant in the west or *E. globoidea* in the east. *E. sieberi* are associated and occasionally predominant. Some drainage area have closed forest II of *Melaleuca* sp.

The *E. nitida*, *E. viminalis* var. *racemosa* and *Banksia serrata* woodlands are similar to those found on the Pleistocene sandy deposits to the east, for example in Barrier and Perry land systems but some of these younger deposits also support forests of *E. bridgesiana*, *E. globoidea* and *E. tereticornis*.

The reason for these two quite district structural and floristic vegetation types occurring sandy deposits is unclear. Some of sands with forests were observed to be underlain by clays and it may be that much of the floristic and structural variation in these areas is associated with depth to clay. Clay layers within the soil profile would reduce drainage rates and increase moisture storage capacity. They would also have higher nutrient availability.

Undulating to flat plains, with others than deep sandy soils, on Tertiary, Pleistocene and Holocene deposits.

Briagolong, Delta, Freestone, Maffra 1 and 2, Moe, Nambrok, Redgum 1 and 2, Sale, Thomson, Trafalgar, Traralgon, Valencia and Yinnar land systems and parts of Clydebank, Dutson, Morass, Nuntin, Perry, Sandy and Wollaston land systems.

(i) Open forests

Most of these plains have been cleared so that it is difficult to determine the variation in structure and dominant species composition which existed prior to European settlement. The remnants of native vegetation, however, suggest that on the plains in the eastern parts of the catchment, the vegetation was mostly a grassy open forest II with *E. tereticornis* predominant; a layered or shrubby understorey probably occurred in wetter areas. Other species which may have been occasionally predominant or associated include *E. bridgesiana; E. bosistana* in *the very east of the study area; E. globoidea; and E. melliodora*, *E. ovata, E. polyanthemos* and *E. viminalis* principally on the modern flood plains.

On the plains in the west where the climate is more humid, there is open forest II, III of *E. ovata* or *E. viminalis*, sometimes shrubby or sedgy. Associated tree species, which may predominate, particularly in the better drained areas, include *E. bridgesiana, E. obliqua* and *E. radiata*. *Melaleuca ericifolia* and/or *M. squarrosa* are common components of the understorey.

(ii) Woodlands

E. tereticornis woodland occurs in a few areas, for example, on sands overlying clays in Wollaston land system. However, it is not known whether this is typical of the structure prior to European settlement.

Dunes and undulating to flat plains with deep sandy soils on Pleistocene and Holocene deposits, except those of the modern coastal zone.

Banksia, Barrier, Rotamah, Sandy, Seacombe, Stratford, and Tyers land systems and parts of the Clydebank, Dutson, Morass, Nuntin, Perry and Wollaston land systems.

On well-drained deep sands, open ferny, heathy or grassy woodland I predominates. It is usually dominated by *E. nitida* and/or *E. viminalis* var. *racemosa* and Banksias errata. The factors determining the distribution of the eucalypt species are unclear but as *E. nitida* is often predominant on the upper slopes of dunes, it may be that it replaces *E. viminalis* var. *racemosa* where the sands are deeper and the moisture availability is lower. On south-eastern Sperm Whale Head eastwards from Rotamah Island, and on eastern Raymond Island, where the mean annual rainfall exceeds about 630 mm, *E. viminalis* var. *racemosa* is accompanied or replaced by *E. botryoides*. Near the coast and on some broad lakeside flats, *E. serrata* is replaced by *E. integrifolia*.

Woodland and open forest I, II with *E. bridgesiana*, *E. consideniana*, *E. globoidea*, *E. ovata*, *E. polyanthemos*, *E. radiata* and *E. tereticornis* also occur, possibly in association with greater moisture availability.

In the heathy understoreys of the *E. nitida, E. serrata* woodland, *Leptospermum myrsinoides* or *Thryptomene micrantha* is generally predominant. *Pteridium esculentum* is generally the predominant understorey species in the *E. viminalis* var. *racemosa, E. serrata* woodlands though this is bought to be a relatively recent change, native grasses being more common about one hundred years ago. The change to the present understorey may have been due, at least in part, to destruction of the grasses by rabbits and to clearing and continual burning (F. C. W. Barton, unpublished data).

Lagoons and intermittent and permanent swamps

Parts of Banksia, Barrier, Clydebank, Delta, Dutson, Morass, Perry, Tyers and Wollaston land systems.

Freshwater swamps produced by high groundwater levels or water perched above clay layers, usually support sedgeland, often with broad fringes of closed scrub. *Lepidosperma langitudinale*, *Schoenus brevifolius* and *Eleocharis sphacelata* are common species of the sedgeland while the closed scrub is usually dominated by *Melaleuca ericifolia* and occasionally by *M. squarrosa*. Freshwater lagoons also often have closed scrub of *Melaleuca ericifolia* of *M. squarrosa* on the margins, with either a tall grassland of *Phragmites communis* or an open herbfield or hydrophytes further form the shore.

Saline swamps also have a zonation of vegetation; however, beyond the closed scrub of *M. ericifolia* on the margins, there are tussock sedgelands dominated by *Ghania filum* or by *G. trifida* on Sperm Whale Head, or a rushland or *Juncus maritimus*. Where salinity is higher, the sedgeland or rushland gives way to herbland of *Salicornia* spp., of which *S. quinqueflora* is the most common.

Modern coastal and lake beaches and dunes

Booran 1 and 2 land systems.

The coastal beaches and berms carry tussock grasses which give way up the seaward face of the foredune to low shrubland or *Acacia sophore*. On the crest and inland slope of the foredune and in the succeeding swale, there is closed scrub of *Leptospermum laevigatum*. As the sands become non-calcareous on the rear dunes, this is replaced by a ferry open woodland of *Banksia integrifolia* with *E. viminalis* var. *racemosa*.

On the dunes, swales, beach ridges and spits east of Lake Wellington, grassy open woodland I of *Banksia integrifolia* occurs where the sands are deeper, mostly in the north. *B. integrifolia* is replaced by *E. tereticornis*, which sometimes forms a grassy open woodland II as well as I, on the shallower sands. Swales with poor drainage usually support closed scrub of *Melaleuca ericifolia*.

Postscript

Sine this chapter was written in 1982-1983, other publications have appeared which are relevant to the vegetation of the Gippsland Lake Catchments. There have been name changes of some species and *Poa Australia* spp. agg. Has been further subdivided into named species. These changes and some new references are given on the corrigendum and addendum on the next unnumbered page.

Corrigendum and addendum

The following botanical names should be changed:

Eucalyptus nitida	To *E. willisii*
E. muellerana	To *E. muelleriana*
E. viminalis	To *E. viminalis* spp. *viminalis*
E. viminalis var. *racemosa*	To *E. viminalis* spp. *pryoriana*
Salicornis spp.	To *Sacocornia* spp.
Alsophila spp.	To *Cyathea* spp.
Casuarinas pp.	To *Allocasuarina* spp.

Poa Australis spp. agg. Has now been subdivided into several species, including:
Poa costiniana, P. clivicola, P hothamensis – sub-alpine woodlands and heathlands; *P helmsii and P. ensiformis* – high altitude, tall open forests; *P. labillardieri, P. tenera* – riverine areas; *P. sieberana* and *P. morrissi* – drier forests; and so on.

A vigorous climber, *Cissus hypoglauca*, often occurs in warm temperate rainforest, but it has not been listed in the preceeding text and in the tables of this chapter.

Subsequent to this chapter being written further relevant studies on Victorian rainforests and on the sub-alpine and sub-alpine regions have been published. These include:

Busby, J. R. (1984)
Nothofagus cunninghamii (Southern Beech) vegetation n Australia. Aust. Flora and Fauna Series No 1, Aust. Govt. Publ. Service, Canberra, 69pp.

MacDougal, K (1982).
The alpine vegetation of the Bogong High Plains. Envir. Studies Div. and Soil Cons. Auth., Ministry of Conservation, Victoria.

Rainforest Technical Committee (1986)
Rainforest conservation in Victoria. A report to the Hon. Joan E. Kirner, minister for Conservation, Forests and Lands, and the Hon. Evan Walker, Minister For Planning and environment, Melbourne.

Seddon, G. (1984)
Characteristics and classification of rainforests. Landscape Aust. 4, 276-85.

Seddon, G. (1985).
The conservation of rainforest. Landscape Aust. 1, 20-31.

Seddon, G. and Cameron, D. (1985)
Temperate rainforests. Landscape Aust. 2, 141-151.

Seddon, G. and Cameron, D. (1985)
Location of temperate rainforests in Victorian Reserves. Landscape Aust. 3, 238-44.

Walsh, N. G. Barley, R. H. and Gullan, P. K. (1984).
The alpine vegetation of Victoria (excluding the Bogong High Plains area). Environmental Studies Project 376. Dept. Conservation, forests and Lands, Victoria.

Tab le 5.1 Common vegetation units associated with the broad land types.

The vegetation units are listed in the order in which they are discussed in the text. Exotic specs are not included.

Broad Land Type	**Vegetation Unit**		**Environment with which unit or individual species associated**
	Structure and predominant species of tallest stratum	**Commonly associated species**	
Uplands – alpine and subalpine areas	Closed forest I and II of *Nothofagus cunninhammii* sometimes with *Leptospermum grandifolium*	**Small shrubs:** *Tasmannia lanceolata, Richea continentis* **Forbs**: *Viola* sp., *Wittsteinia vacciniacea* (near Mt Baw Baw) **Ferns**: *Blechnum wattsil*, *Dicksonia antarctica*, *Polystichum proliferum* **Sedge**: *Carex gaudichaudian*a	Humid gullies in the subalpine zone
	Grassy or shrubby woodland I and II of *E. pauciflora* or, at lower elevation or less exposed sites open forest I, II of *E. pauciflora* with or without *E. rubida*	Relative abundance of understorey species determines structure of the vegetation. Understorey species include: **Tall shrub or tree:** *Nothofagus cunninghammii* (gullies of Baw Baw Plateau) **Smaller shrubs:** *Hovea longifolia*, *Olearia phlogopappa*, *Oxylobium alpestre, O. ellipticum, Tasmannia xerophylla, Leucopogon suaveolens, Wittsteinia vacciniacea* (around Mt Baw Baw) **Forbs:** *Acaena anserinifolia, Celmisia asteliifolia, Leptorhynchos, squamatus, Prunella vulgaris, Ranunculus* spp., *Stellaria pungens, Stylidium graminifolium, Viola* sp. **Grass:** *Poa australis* spp. agg.	
	Open heath or *Hovea longifolia*, *Oxylobium alpestre* and *O. ellipticum* or of *Pultenaea muelleri*, *Helichrysm hookeri* and *Grevillea australis*	Smaller shrubs, forbs and grasses characteristic of the woodlands listed below.	
	Open heath, sedgeland and mossland	Species of all three structure forms ten to occur together with structure being determined by relative abundance. Species include: **Shrubs**: *Baeckea gunniana, Callistemon sieberi, Epacris paludosa, E. microphylla, Hakea microcarpa, Helichrysum hookeri, Richea continentis* **Rushes and sedges**: *Carex appressa, C. gaudichaudiana, Empodisma minus* **Moss**: *Sphagnum cristatum*	Waterlogged and permanently wet areas
	Tussock grassland of *Poa australis* spp. agg.	Species common to both grassland and herbfield. **Forbs**: Brachycome aculeata, Celmisia asteliifolia, Craspedia glauca, Helipterum sp., Leptorhynchos squamatus, Stylidium graminifolium.	Deep soils, often in areas with cold air drainage and/or restricted soil aeration.
	Herbfield of *Celmisia asteliifolia* and *Poa australis* spp. agg.		Predominantly alpine areas
	Feldmark of *Ewartia nubigena*		Areas where organic loams have been eroded to expose stony parent material

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
Uplands – terrain below the subalpine zone	Closed forest II, III, IV of *Nothofagus cunninghammii* or *Atherospermum moschatum* (in east)	**Tall shrubs or small trees:** *Acacia dealbata, A. melanoxylon, Atherosperma moschatum, Hedycarya angustifolia, Leptospermum grandifolium, Pittosporum bicolor* **Shrub**: *Coprosma quadrifida* **Forbs**: *Australian muelleri, Wittsteinia vacciniacea* (near Mt Baw Baw) **Ferns**: *Alsophila australis, Blechnum fluviatile, B. wattsii, Dicksonia antarctica, Histiopteris incise, Polystichum proliferum*	Gullies with high rainfall
	Closed forest II of *Acmena smithii*	(listed in order of abundance from unpublished data of Cameron). **Small trees (6-20 m high):** *Pomaderris aspera, Olearia argcphylla, Elaeocarpus reticulates, Cassinia trinerva, Myoporum insulare* (near coast) **Shrubs (up to 6 m high):** *Coprosma quadrifida, Rubus rosifolius, Solanum aviculare, Olearia irata, Pimelea axiflora, Hymenanthera dentata* **Tree ferns:** *Alsophila australis, Dicksonia antarctica* **Epiphytic ferns:** *Asplenium flabellifolium, A. bulbiferum, Pyrrosia rupestris, Microsorium diversifolium, M. scandens, Hymenophyllum cupressiforme* **Ground ferns:** *Pellaea falcata, Pteris tremula, Doodia media, Lastreopsis acuminate, Polystichum proliferum, Athyrium australe* **Robust, woody climbers:** *Pandorea pandorana, Marsdenia rostrata, Celastrus australis* **Other woody climbers:** *Clematic glycinoides, Smilax australis, Morinda jasminoides, Parsonia brownii* **Climbers with wiry or herbaceous stems:** *Eustrephus latifolius, Geitonoplesium cymosum, Calystegia marginata* **Shade tolerant herbs:** *Sambucua gaudichaudiana, Oplismenus imbeccillis, Gahnia melanocarpa, Microlaena stipoides, Viola hederacea, Dichondra repens, Sarcochilum australis* (ephphytic) **Herbs below canopy gaps:** *Stellaria flaccida, Geranium homeanum, igesbeckia orientalis, Senecia minimus, Urtica incisa*	Gullies at lower elevations
	Woodland to shrubby open forest I, II or *E. dives*, *E. pauciflora* and *E. rubida* or *E. dives* and *E. mannifera*	**Tall shrubs or small trees:** *Acacia dealbata, A. obliquinervia, Exocarpos sp., Polyscias sambucifolius* **Smaller shrubs:** C*assinia aculeata, Coprosma hirtella, Daviesia latifolia, D. ulicifolia, Monotoca scoparia, Oxylobium alpestre, O. ellipticum, Platylobium formosum, Pultenaea juniperina* *Forbs*: *Acaena anserinifolia, Celmisia asteliifolia, Craspedia glauca, Hibbertia obtusifolia, Stylidium graminifolium, Tetratheca ciliata, Viola sp.* *Grasses: Poa australis* spp. agg. **Lily**: *Dianella revolute, Lomandra longifolia* **Fern**: *Pteridium esculentum*	Relatively dry sites at upper elevations (above approximately 900 m); lower moisture status associated with exposure and/or shallow stony soils.

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
	Shrubby or layered open forest III, IV of *E. delegatensis*, sometimes with *E. dives* and *E. rubida*	**Tall shrubs or small trees:** *Acacia dealbata, A. obliquinervia, Cassinia longifolia, Leptospermum grandifolium* (wetter sites), *Polyscias sambucifolius, Pomaderris aspera, Prostanthera lasianthos, Tasmannnia lanceolata, T. zerophila* **Smaller shrubs:** *Cassinia aculeata, Coprosma hirtella, Daviesia latifolia, D. ulicifolia, Olearia lirata, O. Phlogopappa, Oxylobium alpestre, O. ellipticum* *Forms: Stellaria pungens, Stylodium graminifolium, Veronica derwentiana, Viola* sp. **Grass:** *Poa australis* spp. agg. **Lily:** *Dianella tasmanica* **Ferns:** *Blechnum nudum, Dicksonia antarctica, Polystichum proliferum, Pteridium esculentum*	Upper elevation sites (above about 900 m) with high moisture availability; high moisture availability associated mostly with deep soils and protected aspects.
	Open forest III, IV of *E. radiata* and *E. viminalis*	**Tall shrubs and small trees:** *Acacia dealbata, A. melanoxylon, A. mucronata, Lomatia fraseri, Leptospermum grandifolium* (upper elevations), *Polyscias sambucifolius, Pomaderris aspera, Prostanthera lasianthos* **Small shrubs:** *Cassinia aculeata, Coprosma quadrifida* **Forbs:** *Acaena anserinifolia, Dichrondra repens, Hydrocotyle hirta, Prunella vulgaris, Stellaria flaccida, Viola hederacea* **Grasses:** *Poa australis* spp. agg, *Tetrarrhena juncea* **Sedge**: *Carex appressa* **Lily**: *Lomandra longifolia* **Ferns**: *Blechnum nudum, Dicksonia antarctica, Polystichum proliferum, Pteridium esculentum*	Valleys and lower mountain slopes at elevations mostly above 900 m
	Open forest I or II of *Leptospermum grandifolium*	**Tall shrubs or small trees:** *Acacia dealbata, A. melanoxylon, Polyscias sambucifolius, Pomaderris aspera* **Small shrubs:** *Coprosma hirtella, C. quadrifida* **Forbs:** *Acaena anserinifolia, Geranium* sp., *Hydrocotyle hirta, Prunella vulgaris, Ranunculus* sp., *Viola hederacea* **Grasses**: *Poa australis* spp. agg., *Tetrarrhena juncea* **Sedge**: *Carex appressa* **Fern**: *Adiantum aethiopicum, Blechnum nudum, B. wattsii Culcita dubia, Polysticum proliferum, Pteridium esculentum*	Seepage areas and gullies at elevations mostly above 900 m.

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
	Open forest II, III of *E. obliqua* and *E. cypellocarpa*, or in the east, *E. globoidea*, *E. dives*, *E. sieberi*, *E. rubida* and *E. radiata* often associated or occasionally predominant.	**Tall shrubs or small trees:** *Acacia dealbata, A. mucronata, Cassinia longifolia, Bedfordia arborescens Pomaderris aspera* **Smaller shrubs:** *Cassinia aculeata, Coprosma quadrifida, Daviesia ulicifolia, Epacris impressa, Goodenia ovata, Olearia lirata Pimelea axiflora, Platylobium formosum. Pultenacea juniperina* **Forbs:** *Acaena anserinifolia, Senecio quadridentatus, Veronica derwentiana, Viola hederacea* **Grasses:** *Poa australis* spp. agg., *Tetrarrhena juncea* **Lillies:** *Dianella tasmanica, Lomandra longifolia* **Ferns:** *Alsophila australis, Blechnum nudum, Dicksonia antarctica, Polystichum proliferum, Pteridium esculentum*	Relatively humid sites at elevations mostly lower than 900 m
	Open forest III or IV, often layered, of *E. regnans*, sometimes with *E. obliqua*, *E. cypellocarpa* and *E. globulus*	**Tall shrubs or small trees:** *Acacia dealbata, A. valciformis, A. melanoxylon, Bedfordia arborescens, Cassinia longifolia, Correa lawrenciana, Hedycarya, angustifolia, Nothofagus cunninghamii* (high rainfall areas), *Olearis argophylla, Pittosporum bicolor, Polyscias sambucifolius, Pomaderris aspera. Prostanthera lasianthos* **Smaller shrubs:** *Acacia verniciflua, Cassinia aculeata, Coprosma quadrifida, Daviesia latifolia, Goodenia ovata, Olearia lirata, Prostanthera melissifolia, Ziera arborescens* **Forbs:** *Hydrocotyle* sp., *Senecio linearifolius, Stellari,* sp., *Viola* sp. **Grasses:** *Poa* spp., *Tetrarrhena juncea* **Lily**: *Lomandra longifolia* **Sedges:** *Gahnia* spp. **Ferns:** *Alsophila australia, Blechnum nudum, B. wattsii, Dicksonia antarctica, Histiopteris incise, Polystichum proliferum, Pteridium esculentum*	Areas mostly below 900 m in the west and south of the Lakes catchment, with high moisture availability – mostly with protected aspects and deep soils.
	Woodland I, II to open forest I, II with mixed species; predominant species include: *E. albens, E. consideniana, E. globoidea, E. goniocalyx, E. macrorhyncha, E. mannifera, E. muellerana, E. polyanthemos, E. sieberi*	**Tall shrubs and small trees:** *Acacia dealbata, A. mearnsii, Cassinia longifolia, Exocarpos cupressiformis* **Shrubs:** *Acacia falciformis, A. mucronata, A. terminalis, Brachyloma daphnoides, Cassinia aculeata, Coprosma hirtella, C. quadrifida, Daviesia latifolia, Epacris impressa, Monotoca scoparia, Platylobium formosum, Pultenaea juniperina, Xanthorrhoea australis* **Forbs:** *Hibbertia obtusifolia, Stellaria pungens, Stylidium graminifolium* **Grass:** *Poa australis spp. agg., Microlaena stipoides, Themeda australis* **Sedge:** *Lepidosperma laterale* **Lillies:** *Dianella revolute, Stypandra glauca, Lomandra longifolia* **Fern:** *Pteridium esculentum*	Sites below about 900 m with low water availability due mostly shallow stony soils and exposed aspects.
	Grassy woodland II of *E. pauciflora* with or without *E. viminalis* or *E. goniocalyx*	**Shrubs:** *Bursaria spinosa, Brachyloma daphnoides* **Grasses:** *Danthonia* spp., *Poa* spp.	

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
	Woodland I, often heathy, of *E. consideniana* sometimes with *E. cephalocarpa*, or open forest II of *E consideniana* and/or *E. obliqua* and *E. radiata*	**Shrubs:** *Acacia mucronata, Amperea xiphoclada, Banksia spinulosa, B. marginata, Epacris impressa, Hakea microcarpa, Kunzea ericoides, Leptospermum juniperinum, L. myrsinoides, Pultenaea gunnii, Spregelia incarnata, Xanthorrhoea minor* **Grasses:** *Poa* spp., *Tetrarrhena juncea* **Sedges**: *Gahnia radula*	Very silty soils mostly associated with Stewart land system.
	Open forest of *E. tereticornis* sometimes with *E. melliodora*	**Shrubs:** *Acacia mearnsii, Exocarpos cupressiformis, Casuarina stricta, Hymenanthera dentata* **Grasses:** *Danthonia* spp., *Poa* spp., *Stipa* spp., *Themeda australis* **Fern**: *Pteridium esculentum*	Hills at low elevations
	Open forest II, III with one or more of *E. bridgesiana, E. melliodora, E. ovata, E. radiata, E. viminalis* predominant. *E. cypellocarpa* and *E. polyanthemos* sometimes associated	**Tall shrubs and small trees:** *Acacia dealbata, A. mearnsii, A. melanoxylong, Cassinia longifolia, Pomaderris aspera, Prostanthera lasianthos* **Shrubs:** *Acacia mucronata, Bursaria spinosa, Cassinia aculeata, coprosma quadrifida, Goodenia ovata, Kunzea ericoides, Leptospermum junipernum, Olearia lirata, Pimelea axiflora* **Forbs***: Aceana anserinifolia, Dichondra repens, Prunella vulgaris, Stellaria pungens* **Grasses:** *Poa australis* spp. agg., *Tetrarrhena juncea* **Sedge:** *Carex appressa* **Lily:** *Lomandra longifolia* **Ferns:** *Adiantum aethipoicum, Pteridim esculentum*	Alluviated valley floors and adjacent lower slopes at elevations mostly below 900 m.
	Closed scrub of *Melaleuca ericifolia* or *M. squarrosa*	**Shrubs:** *Hakea nodosa, Leptospermum juniperinum, Sprengelia incarnata* **Fern:** *Gleichenia microphylla*	Seepage and drainage, areas, often almost permanently waterlogged, at elevations mostly below 900 m.
	Open health, sedgeland and mossland	Similar species occur in all three structural forms with predominance and hence structural form dependent on the degree of waterlogging **Shrubs**: *Baeckea gunniana, Callistemon sieberi, Epacris paludosa, E. glacilis, Richea continentis* **Rushes and sedges:** *Carex appressa, C. gaudichaudiana, Empodisma minus* **Fern:** *Blechnum pennamarina* **Moss:** *Sphagnum cristatum*	Bogs and seeps at elevations above 900 m
	Closed forest II of *Acmena smithii*	See previous listing	Drainage corridors.

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	Commonly associated species	
Lowlands – hills and sloping terrain with mostly duplex soils	Open forest II In more humid western areas, one or more of *E. bridgesiana, E. consideniana, E. cypellocarpa E. dives, E. obliqua, E. radiata* usually predominant; *E. cephalocarpa* and *E. sieberi* sometimes associated In drier eastern areas, *E. globoidea or E. sieberi* usually predominant; other dominant or associated species include *E. bosistoana, E. bridgesiana, E. cypellocarpa, E. polyanthemos, E. macrorhyncha, E. tereticornis*	**Tall shrubs or small trees:** *Acacia dealbata, A. implexa, A. mearnsii, Cassinia longifolia, Exocarpos cupressiformis* **Smaller shrubs:** *Acacia terminalis, A. genistifolia, A. falciformis, A. mucronata, A. verniciflua, amperea xipholclada, Banksia marginata, Cassinia aculeata, Epacris impressa, Goodenia ovata, Leptospermum juniperinum, Platylobium spp., Pultenaea spp., Xanthorrohea minor* **Grasses**: *Danthonia spp., Microlaena stipoides, Poa australis spp., agg., Stipa spp., Themeda australis* **Sedge**: *Gehnia radula, Lepidosperma laterale* **Lilies**: *Dianella revolute, Lomandra longifolia, Stypandra glauca* **Fern**: *Pteridium esculentum*	
	Open forest II, III with *E. bridgesiana, E. cypellocarpa, E. obliqua, E. ovata, E. radiata, E. viminalis* and sometimes in eastern areas, *E. melliodora, E. polyanthemos*	This vegetation unit is a riparian version of the above unit and includes many of the same species, *Acacia melanoxylon, Bedfordia arborescens, Blechnum nudum, B. minus, Coprosma quadrifida, Kunzea ericoides, Melaleuca ericifolia, Olearia lirata, Pimelea axiflora, Pomaderris aspera, Prostanthera lasianthos* are also found	Lower hill slopes and alluviated valley floors, particularly in the more humid west.
Lowlands – low hills and sloping terrain with sandy soils, mainly on Tertiary deposits	Ferny or heathy woodland I, II usually with more or more of *E. consideniana, E. nitida, E. viminalis* var. r*acemosa, Banksia serrata*	**Tall shrubs or small trees:** *Acacia mearnsii, Casuarina littoralis* **Smaller shrubs:** *Acacia genistifolia, A. terminalis, Amperea xiphoclada, Banksia marginata, Bossiaea cinerea, Bursaria spinosa, Correa reflexa, Epacris impressa, Leptospermum juniperinum, L. myrsinoides, Leucopogon ericoides, L. virgatus, Platylobium formosum. Tetratheca ciliata, Xanthorrhoea australis* **Lily:** *Lomandra longifolia* **Fern:** *Pteridium esculentum* In moister areas, *Kunzea ericoides, Melaleuca ericifolia* and the rushes and sedges *Gahnia radula, Hypolaena fastigata* and *Lepidosperma concavum* are also associated	Deep sands, mostly podzols
	Pen II, III with species include: *E. bridgesiana, E. globoidea, E. muellerana, E. obliqua, E. polyanthemos, E. sieberi*	Associated species similar t those of the open forest II on low hills and sloping terrain with mainly duplex soils. *Banksia serrata* and *Imperata cylindrica* also sometimes associated	Sandy areas with higher moisture availability – possibly associated with greater clay content or clay at depth.
Lowlands – undulating to flat plains with other than deep sandy soils on Tertiary, Pleistocene and Holocene deposits.	Open forest II of *E. tereticornis.* Occasionally associated or predominant species include: *E. bosistoana, E. bridgesiana, E. globoidea, E. melliodora, E. ovata, E. polyanthemos*	Most areas have been cleared and have a high component of exotic species, particularly grasses and herbs. Listed below are the native understorey species which have been found growing in association. **Tall shrubs or small trees:** *Acacia dealbata, A. implexa, A. mearnsii, A. melanoxylon, Casuarina littoralis, C. stricta, Cassinia longifolia, Exocarpos cupressiformis, Melaleuca ericifolia* **Smaller shrubs:** *Cassinia aculeata, Coprosma quadrifida, Hymenanthera dentata, Kunzea ericoides, Myoporum insulare* (near coast)	*E. tereticornis* is typically associated with duplex soils which have some seasonal waterlogging.

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
		Grasses: *Danthonia spp., Microlaena stipoides, Paspalum disttchum, Stipa* spp., *Themeda australis* **Rushes**: *Juncua effuses* } moister areas **Sedges**: *Carex appressa, Gahnia radula* } moister areas **Fern**: *Pteridium esculentum*	
	Open forest II, III, often shrubby or sedgy of *E. bridgesiana, E. obliqua, E. ovata, E. radiata or E. viminalis*	Also a highly disturbed community with most occurrences invaded by exotic species. **Tall shrubs or small trees:** *Acacia dealbata, A. melanoxylon, Cassinia longifolia, Melaleuca ericifolia, M. squarrosa, Pomaderris aspera* **Smaller shrubs:** *Acacia stricta, A. verticillata, Cassinia aculeata, Coprosma quadrifida, Kunzea ericoides, Leptospermum juniperinum, Pimelea axiflora* **Forbs:** *Ranunculus* spp. **Grasses**: *Paspalum distichum, Phragmites communis* **Rush**: *Juncus effuses* **Sedge**: *Gahnia radula*	Modern river terraces and floodplains mostly in the more humid west.
Lowlands – dunes and plains with deep sandy soils on Pleistocene and Holocene deposits (except the modern coastal zone)	Heathy open woodland I of *E. nitida* with *Banksia serrata* and sometimes also *E. viminalis* var. *racemosa*	**Shrubs**: A*cacia oxycedrus, Amperea xiphoclada, Aotus ericoides, Astroloma pinifollium, Banksia marginata, Bassiaea cinerea, B. heterophylla, Casuarina pusilla, Epacris impressa, Leptospermum myrsinoides, Leucopogon ericoides, L. virgatus, Monotoca scoparia, Platysace lanceolata, Ricinicarpos pinifolius, Thryptomene micrantha, Xanthorrhoea australis* **Rush**: *Hypolaena fastigata*	Deep sands, often podzols
	Fern open woodland I of *E. viminalis* var. *racemosa*, sometimes with *E. botryoides* and *Banksia integrifolia*	**Tall shrubs or small trees:** *Banksia serrata, Acacia implexa, Acacia longifolia* **Smaller shrubs:** A*cacia genistifolia, A. oxycedrus, Banksia marginata, Bassiaea cinerea, Bursaria spinosa, Casuarina littoralis, C. stricta. Dillwynia glabberima, Kunzea ericoides, Leptospermum myrsinoides, Minotoca elliptica, Myoporum insulare, Platylobium formosum* **Grasses:** *Imperata cylindrical, Poa* spp., *Themeda australis* **Rush**: *Lomandra longifolia, Scirpus nodosus* **Sedges**: *Hypolaena fastigata, Lepidosperma concavum* **Fern**: *Pteridium esculentum*	
	Grassy or shrubby woodland or open forest I, II; predominant species usually one or more of *E. consideniana, E. globoidea, E. ovata, E. polyanthemos, E. radiata and E. tereticornis* *E. ovata, E. polyanthemos, E. radiata and E. tereticornis*	Species similar to those of the heathy or ferny woodlands listed above, species typical of moister sites such as *Gahnia radula, Lepidosperma* spp. and *Melaleuca ericifolia* are also found.	Sands with higher moisture availability, possibly due to higher clay content or cay at depth.

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
Lowlands – intermittent and permanent freshwater swamps and lagoons	There is usually a zonation of vegetation associated with increased waterlogging and water depth.		
	Open forest I, II of *E. ovata* or *E. tereticornis*		Drier margins
	Closed scrub of *Melaleuca ericifolia* or *M. squarrosa*	*Cotula coronopifolia*, *Leptospermum junipernum* and *Selliera radicans* often associated	
	Closed sedgeland or rushland often with one or more of *Eleocharis sphacelata, Leptidosperma longitudinale, Lepyrodia muelleri, Schoenua brevifolius*		Permanently waterlogged soils.
Lowlands – intermittent and permanent brackish and saline swamps	There is usually a zonation of vegetation associated with increased waterlogging and water depth.		
	Closed scrub of Melaleuca ericifolia	*Leptospermum juniperinum, Myoporum insulare* and *Tetragonia implexicoma* often associated	
	Sedgeland or rushland of *Gahnia filum, G. trifida, Juncua maritimus* Herbfield or *Salicornia quinqueflora* or *S. blackiana*	Species associated with sedgeland and herbfield include: **Forbs:** *Cotula coronopifolia, Disphyma australe, Frankenia paucifolia var. gunnii, Hemicroa pentandra, Mimulus repens, Plantago coronopus, Samolus repens, Selliera radicans, Suaeda australis, Triglochin striata, Wilsonia backhousei* **Grass:** *Distichlis distichophylla* (not in herbfield)	
Lowlands – modern coastal beaches and dunes	Open grassland of *Ammophila arenaria* (introduced) and *Spinifex hirsutus*	**Forbs**: *Cakile maritima, Senecio lautus*	
	Low shrubbed of *Acacia longifolia*	**Shrubs:** *Calocephalus brownii, Helichrysum paralium, Olearia axillaries* **Forbs:** *Apium prostratum, Carpoborotus rossii, Tetragonia implexicoma* **Grasses:** *Spinifex hirsutus* **Climbers:** *Muehlenbreckia adpressa*	Exposed windward slope of foredune
	Closed scrub of *Leptospermum laevigatum*	**Shrubs:** *Acacia longifolia, Leucopogon parviflorus, Myoporum insulare, Rhagodia baccata* **Forbs**: *Tetragonia implexicoma* **Grasses**: *Imperata cylindrical*, *Poa* spp. **Sedges:** *Lepidosperma concavum, Scirpus nodosus* **Fern:** *Pteridium esculentum*	Lee slope of foredune and calcareous rear dunes

Broad Land Type	Vegetation Unit		Environment with which unit or individual species associated
	Structure and predominant species of tallest stratum	**Commonly associated species**	
Lowlands – lacustrine beaches, dune and beach ridges	Ferny open woodland of *Banksia integrifolia* with *E. viminalis* var. *racemosa*	**Tall shrubs:** *Acacia longifolia, A. mearnsii, Banksia serrata, Casuarina stricta, Melaleuca ericifolia* **Smaller shrubs:** *Acacia genistifolia, Bursaria spinosa, Myoporum insulare, Solanum aviculare* **Forbs:** *Tetragonia implexicoma* **Grasses:** I*mperata cylindrical, Poa* spp. **Sedges:** *Lepidosperma concavum, Scirpus nodosus* **Fern:** *Pteridium esculentum*	Non-calcareous rear dunes
	Open woodland I of *Banksia integrifolia*, often with *E. tereticornis*	**Tall shrubs:** *Acacia mearnissi, Casuarina littoralis, Melaleuca ericifolia* (wetter areas) **Smaller shrubs:** *Acacia genistifolia, A. oxycedrus, Nursaria spinosa* **Forbs:** *Carpobrotus rossii, Tetragonia implexicoma* **Grasses:** *Imperata cylindrical, Stipa spp., Zoisia micrantha* **Sedges:** *Lepidosperma concavum, L. gladiatum, Scirpus nodosus* **Fern:** *Pteridium esculentum*	

Vegetation Dynamics

The composition and distribution of native vegetation varies with time, even in the absence of man-made disturbances. In understanding the nature and function of the vegetation, it is necessary to be aware of these natural changes. It is also necessary to understand the processes, in particular those of material and energy transfer, which result in the vegetation being an integral part of the land. It is as a consequence of these processes that disturbances to the vegetation often lead to soil deterioration and altered water regimes.

In this section it is possible to consider only those vegetation changes and processes considered to be relevant to the nature, stability and productivity of the land. The significance of these to particular uses will vary. For example some processes significant to forestry, such as those involved in nutrient cycling, are not likely to be those of most concern in the management of national parks and wilderness areas. In the latter case, changes in understorey composition as a result of control burning or grazing are of more significance. Another limitation to the discussion is the general lack of data on the functioning of local ecosystems. This restricts the discussion to the principles derived from studies in other areas.

Changes in the structure and composition of the vegetation

Changes in the vegetation range from large scale, such as the altered distribution of species and communities associated with major variation in climate, to small scale, for example altered structure and composition within a community as the shorter-lived species senesce and species with greater longevity predominate. There is corresponding variation in the time scales operating; for example, the extended distribution of alpine and sub-alpine vegetation during the last glacial period appears to have lasted from about 32, 000 years before present (BP) to 15, 000 – 10, 000 years BP. In contrast, an *E. pauciflora* community establishers, matures and senesces over a period of 200 to 250 years (Park 1975), and in this time there would be many changes in its structure and composition.

Some changes may permanent, for example, the loss of species following altered environment conditions or the gradual variation in the gene pool of the population as a result of selective pressure exerted by a particular environment. Other changes may be temporary, even though any one phase may be long-lived.

Past environment and vegetation

Past environment conditions influence adaptation and development of species and a knowledge of them may point out factors to which present community composition, structure and processes are adapted. Also, a knowledge of past environments and vegetation provides a dynamic perspective and may enable predictions about future trends to be made.

Our knowledge of past environmental conditions, i.e. of past climates, soils and fire regimes and of the associated vegetation, is far from complete.

Effects of past climates, geophysical events and soils

Theories on the origin, evolution and adaptation of the Australian flora have undergone substantial modification with the development of the concept of a Gondwana super continent and continent drift. The following summary of current ideas is from Barlow (1981).

I it thought that the present Australian flora has evolved from angiosperms extant at the beginning of the breakup of the Gondwana super continent in the middle to late Cretaceous although there was a Miocene migration of Indo-Malayan genera into Australia, particularly the tropical ecosystems, with the collision between the Australian plate and the island arc to the north of Timor.

Barlow considers that at the beginning of the Tertiary ‘climatic conditions were warm and moist’ high rainfall was general in southern Australia and extended through the interior. Temperatures were high in northern and inland Australia (Wopfner *et al* 1974) and warm (20-25° C in southern Australia. The vegetation was more or less uniform structurally, with closed subtropical rainforest being more or less continuous. Some ecological zonation probably existed, with limited differentiation in floristic composition between the warmer and more temperate habitats'. With the separation of Australia from Antarctica, the climate changed (temperatures and precipitation generally decreased) and increased differentiation of the vegetation into the two habitats, one moist and the other more temperate and arid, is believed to have occurred.

Climatic fluctuations within the Quaternary are regarded as generally being more rapid and extreme than during the Tertiary but within the ecological tolerances of the vegetation. Consequently changes within the vegetation have been mostly migrations of communities as conditions varied, for example retreat of tropical rainforest with the onset of glaciation and its expansion during interglacial warming.

Scleromorphy is characteristic of many Australian taxa and it has generally been assumed that it was an adaptation to increasing aridity. It may, however, be a response to soil conditions, in particular to nutrient deficiencies and the suggestion has been made that scleromorphic taxa began to evolve in the Tertiary in nutrient deficient forest sites. Increasing aridity may have been a further stimulus.

Effect of past fire regimes

Little is know about fire regimes in Australia during past millennia. Kemp (1981) suggests that fire frequency was very low during the early to mid Tertiary when rainforest was dominant over southern Australia. Evidence of fire frequency during the Quaternary comes from studies of fine charcoal remains in sediments deposits but most of these do not extend beyond the last 15, 000 years (Singh *et al* 1981).

Singh *et al* have, however, recently obtained a continuous record of vegetation changes and fire history from fine charcoal and pollen in sediment cores taken from Lake George in New South Wales and Lynchs Crater in N.E Queensland. The cores go back approximately 350, 000 years and 140, 000 years respectively, although these dates and those assigned to the vegetation changes, have not been obtained by direct dating beyond the ^{14}C limit of 37, 000 years. The warmer interglacial and the cooler glacial periods have been inferred from the different taxa and this glacial-interglacial sequence and compared with the 18O (oxygen isotope) ocean palaeo-temperature sequence of Emiliani and dated by Shackleton and Opdyke (Singh *et al* 1981).

Their analyses indicate that there has been a relatively high fire frequency and/or intensity since the beginning of the last inter-glacial period, approximately 128, 000 years Bp. There has also been an increase in the eucalypt and other myrtaceous species and a decrease in *Casuarina* and cool temperate area taxa. The decline of the fire sensitive *Casuarina* and cool temperate tax is attributed to the increased fire frequency.

On the basis of increase fire activity, Singh *et al*. suggest aboriginal occupation of the area around Lake George during the last interglacial, i.e. about 120, 000 years ago. This would indicate that firing associated with aboriginal occupation led to the proliferation over areas of Southern Australia of eucalypt and other myrtaceous taxa during the Holocene and a reduction in *Casuarina* and other cool temperate species.

The suggestion that the profusion of eucalyptus has been encouraged by increased fire frequency is supported by the fact that in a eucalypt forest with *Nothofagus* and a cool temperature understorey, the *Nothofagus* will replace the eucalypt in the absence of fire. In addition frequent firing or particularly severe fires will eliminate *Nothofagus* from a site and allow the establishment of a eucalypt forest. Howard and Ashton (1973) consider that cool temperate rainforest dominated by *Nothofagus* could grow in S.E. Australia at a number of localities, from near sea level to about 1450 m, which now support wet sclerophyll forest; *Nothofagus* may have been lost from these sites due to frequent firing and not re-established due to its low capacity for dispersal.

Data on past fire frequency in the Lakes catchments is lacking. If, however, as Singh *et al* suggest, aboriginal occupation in S.E. Australia was some 120, 000 years ago, then it is possible that firing resulting from their activity has been part of the environment of the Lakes catchment prior to the last glacial period.

The presence of a lignotuber which allows coppicing after fires in Victorian populations of *Nothofagus* but not Tasmanian populations (Howard 1973) suggests that the forests in the Victorian high country have been subjected to greater firing frequencies than those in Tasmania.

Whatever the past fire regime, however, it seems on the basis of the vegetation studies referred to, that certain practices, such as frequent firing, may have implications for the long term development of the vegetation. This will be discussed subsequently.

Short-term temporary changes

Changes that take place in a community as it matures or as a disturbance are known as successional changes. In the past the assumption has tended to be that a community functions in an integrated way and that there is an orderly and predictable change to another community type (Odum 1969). However, recent work questions this concept of succession, for example Noble and Slatyer (1978) view the community as an association of species in composition may occur with time but the change may not be orderly, depending on the 'lifer strategy' of the individual species and on the nature and frequency of the environmental perturbation.

Noble and Slatyer (1977, 1978, 1981) have shown that, from a knowledge of particular attributes of a species which they term 'vital attributes', it is possible to predict changes in community composition with time. They list four vital attributes which allow a plant to establish and remain at a site: the method of arrival or persistence of seeds and/or propagules at a site; the ability of mature individuals to survive through a disturbance; conditions required for establishment and growth to maturity; the length of time to important life stages.

For example, *E. pauciflora* can regenerate vegetatively from epicormic buds as well as from seed, can survive a disturbance such as burning and can establish only immediately after a disturbance. It produces seed after five years and individual trees die after about 200 years. From this information it is possible to predict that *E. pauciflora* will not survive at a site in the absence of some form of disturbance beyond about 200 years.

The shrub species of the *E. pauciflora* woodland are able to establish immediately after disturbance from seed stored in the soil, reach reproductive maturity at 5 years, and have a longevity of 40 years. Visible seed will remain in the soil for 40 years following the death of mature individuals, after which time there is no survival mechanism. Consequently, if a disturbance and re-establishment do not occur in about 80 years, the species will be lost from the site.

Grasses can establish at any time from seed dispersed from surrounding areas or from mature individuals at the site. They will, therefore, continue to exist at the site indefinitely.

The vital attribute data indicates that if the firing frequency in an *E. pauciflora* woodland is greater than approximately 80 years, shrub species will tend to be lost and a grassy understorey will predominate while at frequencies of greater than 200 years, the community will tend to become a grassland. Firing at intervals of less than 80 years will maintain the snow gum woodland with a shrub/grass understorey.

The combined effect of firing frequency and grazing by sheep can also be predicted. It has been observed that if grazing pressure by sheep id moderate, the grass cover will be reduced allowing some space for shrub species to regenerate (Bryant 1969 and 1971). At this grazing intensity shrubs will therefore be able to regenerate at an stage, irrespective of whether the community is fired, so that a shrub understorey will tend to remain even with protection from burning. With heavy grazing pressure, *E. pauciflora* regenerating after fire from either seed or coppice may be grazed, effectively preventing its re-establishment. Under these conditions, a shrub grass community without *E. pauciflora* will tend to establish.

Prediction of community change under given disturbance patterns could be made in a similar manner for component species were known. Vital attribute data, however, are known for relatively few Australian species (Gill 1981) and variability within a species is a complicating factor.

Processes of energy and material transfer

Processes involved in the transfer of material and energy to, within and from the vegetative community and its environment are responsible for biomass production and for the interactions of the biomass with other land features. These processes are:

(i) primary production and energy flow;
(ii) nutrient cycling;
(iii) water flow.

The rates of each process and the amounts of materials involved vary according to the environment and the structure, species composition and the age of the community.

Gross and net primary and energy flow

Solar energy is used by plants in photosynthesis to produce organic compounds, which can later be broken down with the release of energy. The total amount of organic matter produced is the gross primary production. Net primary production is the amount of organic matter stored, that is the difference between the amount of organic matter produced by photosynthesis and used in respiration. Net primary production not only includes organic which increases the biomass of the plant but also that which dies, falls as litter or which is consumed by herbivores insects and micro-organisms.

Net primary production (NPP) varies with community age; for example, maximum NPP in a stand of *E. oblique* occurred at approximately 40 years (Attiwill 1979). It is interesting to note that this was plant biomass, approximately 0.5 kg m^{-2} yr^{-1}, occurred, and that by age 80 years, the rate was less than 0.1 kg m^{-2} yr^{-1}; This eight fold difference is of importance to timber production. The decrease in biomass accumulation beyond 40 years was partly the result of the reduced NPP but it was also the result of a change in the way the annual NPP was apportioned – the proportion directed towards an increase in the biomass was reduced while the amount in dead trees and litter fall, increased.

Total biomass production varies between forests and any given age, being strongly influenced by environments factors such as the annual temperature and moisture regime and the availability of nutrients. For example, Park (1975) has estimated above ground biomass in and *E. delegatensis* forest to be approximately 620t/ha compared with only 330 t/ha in an *E. pauciflora* community.

Nutrient cycling

Nutrients exist within the environment in the soul and soul parent material, in living and dead biomass and in the atmosphere. Nutrient cycling is the movement of nutrients within and between these components.

Within the soil, nutrients may be available or unavailable for plant growth. Unavailable nutrients are held tightly within molecules, usually of primary or secondary minerals or of organic compounds. Such nutrients become available following decomposition of organic matter and weather of minerals.

A complete nutrient cycling study involves measurement of nutrients in the various components and the rate of transfer between components, not only at one point in time, but as the community matures. Most nutrient cycling studies in Australian ecosystems are far from complete, examining one or two components only, mostly biomass and litter, at one particular stage of ecosystem development. The rate of nutrient input from weathering of parent material is rarely measured, but this has been done by Feller (1981) in the Maroondah catchment.

There appear to be no nutrient cycling studies of ecosystems within the Gippsland Lakes catchments although studies have been made for similar vegetation types elsewhere, Attiwill *et al* (1978), Guthrie *et al* (1978) types elsewhere Attiwill *et al* (1979, 1980) measures biomass, litter production and associated nutrient pools, the rates of nutrient transfer between the biomass and soil components and the rate of nutrient input in rainfall, in an *E. obliqua* forest north of Melbourne, with some of the measurements being taken over a 22 year period. In the same general area Ashton (1975) has determined the nutrient composition of litter and the rate of litter all and decay from pole, spar and mature stages of *E. regnans* and from the associated understorey species. Park (1975) has estimated the biomass of *E. delegatensis* and *E pauciflora* communities in the Snowy Mountains and measured rates of litter fall and nutrient transfer for these communities. Howard (1973) has measured the biomass and decomposition rates of litter in a *Nothofagus* forest at Mount Donna Buang.

From these studies it is apparent that the total amounts of nutrient held within the biomass and the rates of transfer of nutrients between the biotic and abiotic environment vary with community type and stand age.

The rate of which organic matter is returned to the soil in litter and decomposed, not only affects nutrient cycling but soil structure and hence, water holding capacity and cation exchange capacity. It is therefore significant for soil stability and productivity.

Water balance

Water inputs into an ecosystem can be stored in the soil or lost through evaporation, transpiration, overland flow and seepage through the soil. The fate of precipitation depends on it amount and intensity, topography, geology, soil, vegetation and other climatic factors, particularly wind.

Precipitation had potential energy and potential solvent power, which can be utilized as it moves into, through and out of the system, to erode and transport soil particles and to dissolve chemical compounds. 'The vegetation…acts to minimize these degrading activities by the utilization of solar energy in transpiration. Thus streamflow is reduced, and a variety of other mechanisms allow the ecosystem to absorb the kinetic energy of flowing water while yielding a minimum of eroded material' (Bormann and Likens 1979). Bormann and Likens also regard the following as actual or potential effects of transpiration:

(i) Reduction in water output helps maintain nutrients with infiltrating water.
(ii) Transpiration acts as a driving force for nutrient cycling drawing soluble nutrients to and into the plant. This process returns leached nutrient to the surface, thus reducing nutrient loss.
(iii) Transpiration may reduce water-logging.

Transpiration at any given site is influenced by structure and age of the vegetation, as shown for example by Brookes and Turner (cited in Langford and O'Shaughnessy 1977) who measured rainfall, throughfall, streamflow and soil moister changes in *E. regnans* forests of different ages. They found that the mature forests consumed less water than the regrowth forests.

The effect of fire on the soil and vegetation

The effect of fire and its long term implications are considerable concern to those interested in maintaining native ecosystems and their productivity and diversity.

An increasing amount of research ahs been devoted to these questions but there are many areas in which information is lacking. Raison (1980) points out that so far, 'Australian research has only examined the affect of fire on particular components of the nutrient cycle, for example, the litter component, and that no study has evaluated the significance of the separate effects of fire on the nutrient budget of entire plant communities in which there are many regulatory and compensating ecological processes. For example, nitrogen lost in smoke may be replaced by N-fixing legumes (Shea and Kitt 1976, Halisay and Pate 1976) which proliferate after burning'.

Rowe and Hagel (1974) also stress the need for careful interpretation of results of studies which examine only a single aspect of firing, due to the complex interactions between processes within ecosystems.

Assessment of the significance of nutrient loss by fire for particular ecosystems is also limited by the general lack of data on nutrient cycling in the undisturbed condition.

Despite these gaps in knowledge, work does suggest some possible consequences of firing and these should be considered. No data are available from ecosystems within the Lakes catchments but relevant work has been done in similar communities.

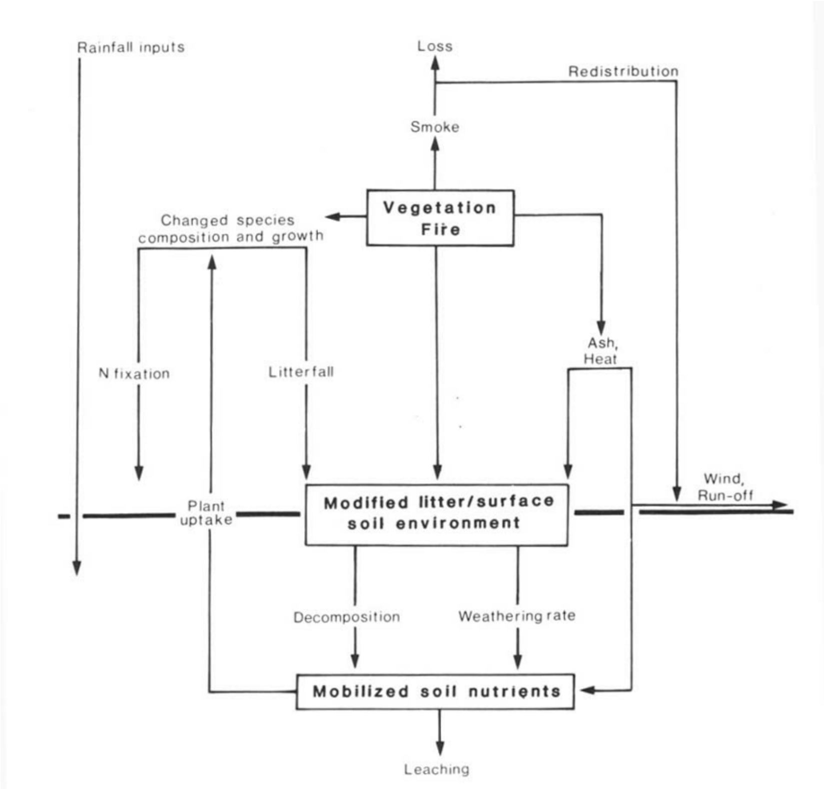


Figure 5.1 – The potential effects of fire on nutrient cycling [Source: Raison (1980)

Effect of fire on soil structure

Humphreys and Craig (1981) have considered the effects of fire on soul structure. Organic matter and the fine mineral fraction including clay and sesquioxides are largely responsible for aggregation in soils. Organic matter is oxidized (i.e. decomposed) slowly at 200°C and very rapidly at 400°C, while heat tends to aggregate the fine mineral fraction, this process being irreversible above 400°C. The effect of fire on structure depends, therefore, on the temperature reached. Craig (cited in Humphreys and Craig 1981) in a study of the effect of temperature on the structure of red clay loam, found that the strength of the surface aggregates was slightly reduced after a fire of sufficient intensity to breakdown the organic matter. However, the strength of the subsoil aggregates increased.

The maintenance of structure is important for promoting infiltration of water and is even more critical after fire when the vegetation and litter have been removed. It seems that in many soils structure is maintained or enhanced by firing. However the loss of cover may increase raindrop impact, thus promoting breakdown of aggregates.

Effect of fire on nutrient pools and cycles.

Studies related to the effect of fire on nutrient cycling have been reviewed by Raison (1980) who summarize the potential effects, both on processes and on the site characteristics. (Figure 5.1).

Biomass is one of the major components of the nutrient pool. The immediate effect of fire is to mobilize the nutrients within this component. The actual quantities of nutrients release will depend on the nutrient content of the biomass, which varies according to species and age, and on the intensity of the burn, that is, on the degree to which the biomass is destroyed. As an example of the amounts of nutrients that can be mobilized Humphreys and Craig (1981) calculate that complete burning of mountain gum/peppermint windrows left after logging, could leave behind an amount of phosphorous equivalent to that in 12.5 t/ha superphosphate.

There is a high potential for loss of such nutrients through volatilization and particulate loss in smoke, through leaching or through removal of residual ash by wind and water. Raison and Woods (cited in

Raison 1980) calculate that about 60% of the N, 60% of the S and 50% of the P contained in eucalypt litter were lost in smoke during a fire of low intensity. Harwood and Jackson (1975) calculated losses to the atmosphere of 18% P, 17% K, 12% Ca and 19% Mg from the slash burning of the residue from a logged, mixed forest in Tasmania.

Rowe and Hagel (1974) found that there was a significant increase in the Ca, K, Na and SO_4 leached from forest litter after a fuel reduction burn and that these nutrients were leached beyond a depth of 5 cm. The degree to which nutrients release by burning will be leached depends on rainfall, infiltration capacity of the soil and cation exchange capacity which depends on the clay and organic matter content. When organic matter is destroyed by fire, it is left to clay particles to adsorb released nutrients. Nutrient leaching after fire is therefore likely to be relatively severe on sandy soils.

Loss of nutrients through surface wash would be greatest when heavy rains follow burning before vegetation re-establishment, for example as noted by Park (1975) in sub-alpine areas following summer fires, would increase the potential for this type of loss.

Beadle (1962) has suggested that the low phosphorous content of may soils in Eastern Australia could be attributed to a long history of burning and erosion.

Ashton (1976) noted that the wet sclerophyll forests on southern slopes overlying granite at Beenak had an accumulation of phosphorous in the top 12 cm of soil; such an accumulation was absent from the dry sclerophyll hypothesis, Ashton suggested that the difference may be with a loss of phosphorous occurring during the burn and in subsequent hill wash and soil creep downslope. Alternatively, loss of phosphorous may have occurred through sheet erosion during periods of past aridity when the slopes with exposed aspects may have been poorly vegetated.

Ashton (1981) also points out that there is a self-perpetuating spiral ensuring increased firing. Exposed aspects dry out more rapidly and therefore carry fire more easily and more often; the resultant loss of nutrients tends to encourage the growth of vegetation which is highly flammable due to volatile oils and low mineral content (Vines 1981).

Effect of fire on community composition and maturity

The effect of fire frequency, intensity and seasonality on community composition depends on the survival capacity, reproductive strategy, dispersal mechanisms, establishment requirements and longevity of the component plant species. An example of the effects of different fire regimes has already been discussed with respect to the sub-alpine woodlands in the section ‘Short-term temporary changes’.

Frequent burning will obviously also prevent a community reaching maturity.

Relationships between processes and management practices

The foregoing discussion indicates the complexity and inter-related nature of many processes within the vegetation. As a consequence of this inter-relation, individual processes and changes need to be considered as part of the functioning of the whole ecosystem over time and not in isolation.

Discussed below are broad implications for management processes discussed in the preceeding sections.

Long-term changes in the vegetation due to fire

The work by Singh *et al* indicates that in eastern New South Wales there has been a decrease in the fire sensitive *Casuarina* and cool temperate rainforest communities and an increase in fire tolerant sclerophyllous eucalypt communities since the last interglacial period, coincident with an increase in fire frequency/intensity.

It is possible that the present fire regime in the Lakes catchment is similarly encouraging the development of fire tolerant sclerophyllous species at the expense of sensitive species such as *Nothofagus cunninghamii*.

The fire regime influences the development of the vegetation not only through the varying susceptibility of species but also through fire effects on soil erosion and nutrient cycles and hence on soil fertility.

The long-term effect of repeated fuel reduction and regeneration burns on nutrient pools within the different forests is virtually unknown due to the lack of data on the rate at which nutrients are lost following fire, the amount of nutrients within the soul available to plants, the total reserves of nutrients in unavailable form and the rate at which nutrients become available through weathering decomposition.

Implications of short-term changes in the vegetation for fuel reduction burning

The work by Attiwill (1979) and Park (1975) indicates that litter production varies with the age of the community; they further suggest that litter return in the mature forest plays a role in maintaining the ecosystem.

Observations on understorey species following fire suggest that fuel reduction burns may in fact maintain the species which are fire dependent. For example, Purdie and Slatyer (1976) found that he shrub component of a dry sclerophyll forest, which included *Daviesia mimosoides, Dillwynia retorta* and *Acacia genistifolia,* would senesce and be lost if there was an interval of approximately 20 years between fires. With frequent firing, the shrubs tend to regenerate and remain a problem, prompting further burning. It would seem that without firing, the shrubs tend to regenerate and remain a problem, prompting further burning. It would seem that without firing, flammable shrub species will gradually disappear thus reducing the fire hazard.

Changes with time both in litter production and understorey composition, could possibly be used in management strategies; for example by developing a mosaic of different aged communities, large continuous areas with a highly flammable understorey and litter layer could be avoided and hence reduce the need for fuel reduction burns. (See Park 1975).

Effects of clearing on processes of material and energy transfer

Removal of native vegetation, particularly forests, can result in major changes to the local and regional water balance which in turn can affect erosion, salting and leaching.

Trees transpire larger volumes of water than most crops or pastures, being perennial and having deeper root systems. Consequently soils under forest will generally be drier, with a greater capacity for accepting and storing water. Deep percolation and run-off increase as a soil becomes saturated, so that water loss by both processes tends to be greater under pasture. Increase overland flow often promotes erosion and increased deep percolation can promote water-logging and mobilization of salts which may have accumulated in the regolith.

Infiltrating water also has the capacity to remove nutrient ions such as K^+ and Ca^{++} from soils with a low cation exchange capacity, particularly sandy soils. Increased infiltration caused by replacement of forest or other deep-rooted vegetation, particularly in areas of high rainfall, could result in significant cation loss from the surface layers of such soils. Also, the lack of deep roots would mean that any cations leached from the surface layers could not be returned.

Significant nutrient loss on clearing could also occur directly when the vegetation removed contained a high proportion of nutrients within the ecosystem. This problem is also particularly likely in areas with deep sandy soils.

Effects of logging on vegetation composition and on processes of material and energy transfer

The effects of logging on community structure and species composition depends on factors such as the extent of clearfelling versus selective logging, the age at which trees are harvested and whether there is a regeneration burn.

Clearfelling results in even-aged stands of regenerated timber; selective logging allows maintenance of mixed-aged stands, although the tree stratum of the mature stand usually becomes more uniform with respect to species composition.

As logging is usually carried out when trees reach a particular stage of growth, areas of forest do not usually reach full maturity unless reserves are set aside.

The establishment of exotic plants and weeds is aided by the development of logging roads and tracks which reduce canopy cover.

Logging results in a reduction in the transpiring biomass and the effect on the water balance are similar to those discussed above for permanent clearing. However, the increase in deep percolation and/or run-off is temporary.

Removal of timber from a site will result in the removal of nutrients. The significance of this, however, depends on the rate of removal, on the total reserve of nutrients and on the rate at which stored nutrients are made available for plant growth. Little id known about these factors for ecosystems of the Lakes Catchments.

The implication of processes for the concept of multiple use

Various land uses much contend with the same broad properties and processes of the land, but these are variously manipulated to provide maximum benefit for each use.

Multiple use of land aims to combine uses. However, since each use requires specific values of properties and processes, conflict is inevitable and can only be resolved by compromising the maximum potential of the resource for one or more uses.

An example of combining timber production with flora and fauna conservation. Efficient timber production seeks to maximize the amount of usable timber per hectare using even-aged stands mostly of singe tree species with a rapid growth rate and millable timber. Stands are mostly harvested and regenerated once maximum accumulation of biomass has been achieved; that is, timber production is primarily based on the productivity aspect of plant growth. Fuel reduction burning is used in some forests to reduce the incidence of wildfires and consequent loss of the resource.

Flora and fauna conservation, on the other hand, would usually seek to maximize the floristic and structural diversity of forests. It would allow communities to mature and senesce, that is, they would be maintained beyond their age of maximum biomass accumulation. Burn programmes to reduce litter and shrub composition would not usually be part of the management strategy.

Consequently, the value of production forests for flora and fauna conservation may not be as great as those managed specifically for conservation. Such a compromise is not necessarily to be avoided, but the possible reduction in the maximum potential of the land for conservation should be recognized.

An alternative multiple use which tends to produce 'moderate quality and yield over all the landscape' (Odum 1969) is to divide the landscape into units, each of which is managed so as to obtain maximum productivity and quality for a specific use. The preference for this alternative will depend on the land type, processes and proposed uses.

Implications and processes and changes in the vegetation for conservation management

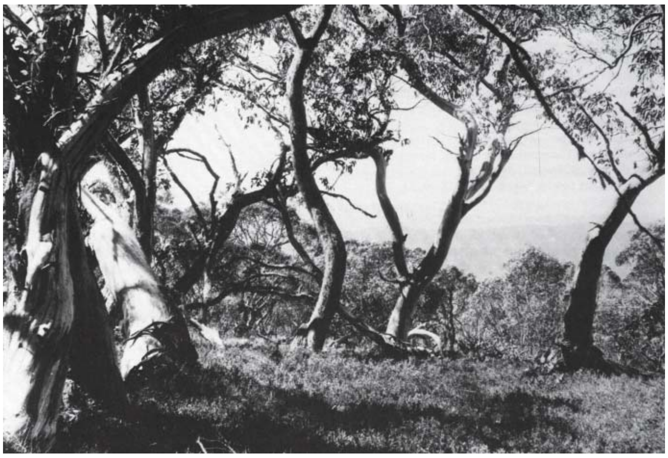
The maintenance of diverse plant species, communities and gene pools is often the aim in establishing conservation areas. This is a realistic ambition only if it is recognized that, even in the absence of disturbance by man, communities will change with time, so that management aimed at preserving particular communities or stages in plant communities, may be just as 'non-natural' as other manmade disturbances.

Conclusion

Conflict over land management strategies is inevitable even when there is agreement as to the type of land use, for example forestry, nature conservation or recreation. This is due to the variety of processes operating and the range of strategies that can be implement to control them, each with its own significance for the vegetation.

The effects of fire on processes affecting plant succession in a flora reserve are an example. As discussed, different regimes will favour one group of species at the expense of others, such as shrubs rather than grasses. This will have further implications for the ecosystems by affecting processes including organic matter accumulation and nutrient and water balances. The fire regime also affects soil erosion and nutrient loss and hence soil fertility and this will affect future plant communities.

An understanding of the processes, their inter-relationships and their significance for the functioning of the ecosystem over time cannot resolve these conflicts. It can, however, lead to rational management decisions that consider the long-term implications as well as the short-term benefits that may be gained from a particular management strategy.



Sub-alpine woodland of* E. pauciflora *with a shrubby understorey

Leptospermum laevigatum *closed scrub found on calcareous sands of the modern coastal dunes*

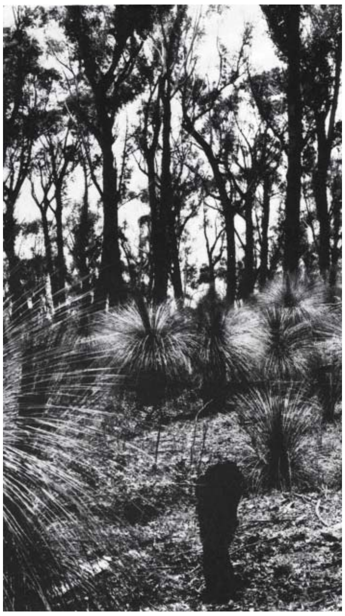
Freshwater swamp with sedgeland bordered by a woodland of **Eucalyptus tereticornis**

Forest of **E. sieberi**

Heathy **E. nitida, E. viminalis** *var*. **racemosa** *woodland found on deep sandy soils in the lowlands**

Forest of **E. tereticornis** *near Briagolong. Such forest was once widespread over the plains with duplex soils.*

An alpine herbfield, Mount Hotham



Xanthorrhoea australis *growing in a woodland found on slopes below 900 m elevation.*

6. LAND USE

History Of Development

Discovery of the Port Albert harbour in 1841 provided an export outlet for cattle from the Gippsland region and more ready access for settlers. Occupation of the more open eastern plains and valleys followed quickly and was largely completed by 1844. At first cattle were grazed extensively on bush runs, but as the open forests and woodlands with better souls were progressively cleared, farming became more diversified to include wool and fat-lamb production, limited cropping and dairying.

Following gold discoveries at Ballarat and Bendigo, Victoria's population was swollen by prospectors who moved into Gippsland in the 1850's when most of the major fields there were opened up. Development of the high rainfall, heavily timbered country I the west proceeded slowly with settlers gradually moving in from Westernport Bay.

In the period 1870-1900 dairy farmers settling the Strzeleckis largely destroyed the high quality *Eucalyptus regnans* forests. In the 1930's dairying had become uneconomic in the steeper, eastern part of the range because of weed, pest animals, isolation from transport and markets, increasing labour costs and lower returns. Much of the area has now reverted to understorey scrub. From the late 1940's onwards, many abandoned and marginal farms were bought for replanting to *E. regnans* and pines.

Shipping serving Port Albert and the Gippsland Lakes provided most of the outside communications and transport until the railway from Melbourne reached Sale in 1879 and Bairnsdale in 1888. after that development accelerated.

Over the period 1850-1914, significant quantities of timber from the foothills were used for gold mining and the expansion of mining towns – particularly around Walhalla, Omeo, Brookville and Cassilis. Concurrently, durable timbers of the coastal plains, notably *E. tereticornis, E. bosistana, E. melliodora, E. polyanthemos* and *E. sideroxylon*, were in demand by pastoralists, and for the new railway line. Also, with the establishment of rain transport, it was used for extensive building, paving blocks and general construction work in Melbourne. Timber from *E. regnans* forests had been cut for split palings and shingles from the earliest days of settlement, but only after 1910 were difficulties of drying and seasoning overcome. Milling of *E. regnans* and *E. delegatensis* in the Thomson and the La Trobe River catchments then followed quickly. Significant quantities of saw logs were harvested in the 1930's from near Walhalla and Mount Baldhead.

A pulp and paper mill was built at Maryvale in 1936 to use waster wood from logging to manufacture packing paper and paperboard products. Planting of radiata pine (*Pinus radiata*) for these products began in 1950.

Disastrous bush fires in 1926, and more extensively in 1939, destroyed most of the *E. regnans* and *E. delegatensis* forests of the Thomson and La Trobe River catchments. The 1939 fires also burnt significant areas of *E. delegatensis* forest at the heads of the Wongungarra and Dargo Rivers. Most of the burnt areas now carry advanced ash regrowth.

Following the salvage of *E. regnans* timber burn in the 1939 fires in Central Victoria, many sawmills shifted to Gippsland, notably to Heyfield and Swifts Creek in the late 1940's, after which logging was concentrated on the *E. delegatensis* timber at higher elevations. In the 1950's more mills were established at Bullumwaal, Ensay and Buchan.

In 1962 logging has extended along the Tamboritha Road north of Licola to Mount Tamboritha and later eastwards towards mount Kent and northwards towards Mount Howitt.

Construction of a reservoir on the Macalister River at Glenmaggie, later called Lake Glenmaggie, commence in 1919 and water channeled from it was first used for irrigation in 1925 at Boisdale. In the 1950's the irrigation system was extended to country around Nambrok and Dension and later to land near Heyfield and West Boisdale, and north and east of Sale. In 1957 Lake Glenmaggie was enlarged to cope with the additional demand for water from the expanded area which was called the Macalister Irrigation District. In 1979 work commenced on the Thomson River dam, a storage that will divert water to Melbourne but could also provide for irrigation in the La Trobe River Valley and may result in less water flow through the Gippsland Lakes.

Brown coal deposits were first mined and electricity generated in the La Trobe Valley in the 1920's. Oil and gas processing commenced at Longford in the 1960's.

After World War II, with increasing population, higher wages and more leisure time tourism and recreation have become progressively more important, particularly around the Gippsland Lakes and Mount Hotham.

The main forms of land use at present are agriculture, forestry, honey production, nature conservation, recreation, residential use, mining and water supply. Minor areas are used for sewage disposal, Royal Australian Air Force training and service easements for oil and gas pipelines and SEC transmission lines.

Present Land Use

Agriculture

About one third of the area has been cleared, mostly for agriculture. In addition, an area of uncleared alpine and forest land of nearly the same size is leased for non-intensive grazing of beef cattle.

Grazing of cattle and sheep is the most widespread form of agriculture. In the higher rainfall areas to the west and in the Macalister irrigation District, dairying is generally the most important enterprise and large numbers of beef cattle are also carried. In the drier country from Stratford eastwards, beef cattle are usually run with sheep, and dairying is confined to the irrigated alluvial soils of the Mitchell River flats. Although sheep are spreads throughout the agricultural areas they are concentrated on the plains between Rosedale and Lakes Entrance and in the Princess Highway where the mean annual rainfall is between 750 and 1000 mm.

Most of the pastures have been improved by the application of superphosphate. In the higher rainfall areas to the west, in the Macalister irrigation District and on the irrigated alluvial flats, particularly those of the Mitchell River, sown pastures are generally established. In the drier, eastern areas improved pasture species are seldom sown, largely because native perennial grasses, refreshed by frequent summer rain, tend to persist.

Cropping is largely for vegetable growing and for the production of grain for stock feed. Vegetable growing is relatively important, amounting, for example, for 11% of the State's production in 1975. Much of the cropped areas is irrigated. Potatoes are grown mainly around Mirboo North and Thorpdale. Other vegetables, harvested from alluvial flats in the Bairnsdale area and to a lesser extent at Briagolong and Cowwarr, include predominantly cool season crops such as broccoli, cabbage and cauliflower, and summer crops of beans, capsicum, sweet corn and tomatoes. Small areas of grain crops are principally maize on the irrigated river flats, and barely and wheat on the plains south of Heyfield and between Meelieu and Goon Nure.

Forestry

Forests cover about two thirds of the catchments. Timber productivity is greatest in the ash open forests, which are dominated by *E. regnans* and *E. Delegatensis* with limited *E. nitens.* In the Thomson and La Trobe River catchments most of these forests are in an advanced stage of regrowth following the 1939 fires. Further eastwards about one third of the ash forests are mature, the remainder being younger regrowth resulting from past logging or wildfires. The timber is harvested as saw logs and pulpwood. It is of attractive appearance with few defects, can be seasoned for flooring or cabinet making or used to make high quality paper.

Other open forests also provide large quantities of timber from species such as *E. oblique, E. cypellocarpa, E. sieberi, E. globoidea, E. radiata* and *E. viminalis.* This timber is used for house farming and general construction and for the manufacture of paper and paperboard. Open forest with species such as *E. macrorhyncha, E. polyanthemos, E. globoidea, E. sieberi* and *E. albens* provide only minor quantities of timber mainly for durable post, poles and firewood. The woodlands and open woodlands produce little timber, suitable only for firewood.

Pines (mostly *Pinus radiate*) are grown extensively in the La Trobe Merriman Creek and Avon River catchments in the Strzelecki Ranges ad around Loch Valley, Longford and Stockdale. In well drained sites plantations are relatively productive and supply high quality saw logs suitable for most timber needs including poles, fence posts and wood pulp.

Honey production

Bees father nectar and pollen from flowering plants, using the nectar to make honey and the pollen and some of the honey as food. Eucalyptus provide most of the nectar and pollen required but many other plants, both native and introduced, are also of value particularly as a food source, although the honey produced is often of inferior quality.

Water, the other main requirement of bees, is generally available and eucalyptus are in flower in some part of the region for most of the year, with winter the leanest season. However, the changeable climate and shortage of eucalyptus that yield the popular light coloured, mild flavoured honey has induced many apiarists to bring bees into Gippsland only when conditions are favourable. Other major problems in the area for beekeepers are bushfires and the clearing of eucalyptus for softwood forestry or agriculture.

Important non-eucalypt native plants include *Acacia botrecephala* and *Banksia integrifolia*, which are particularly useful as they flower during winter and *B. serrata*, *Daviesia latifolia* and *Melaleuca ericifolia*. Amongst exotic species of value are *Salix sp.*, *Cirsium vulgare*, blackberry (*Rubus* spp. agg), other berry, vegetable crops, and the clovers. Although yielding far less nectar than eucalypts, clovers provide a high grade, mild and light coloured honey.

Nature conservation and recreation

The catchment contains varied flora and fauna of great scenic and scientific value, environments ranging from the subalps through the humid mountain forests to the drier foothills, the Gippsland Plains and the ocean beaches.

Some 13 to 14 per cent of the area is in current or proposed reserves for nature conservation and recreation, mostly National Parks or States Parks but also Flora and Fauna and other reserves. In general these areas provide for the conservation of the natural environment and outdoor recreation.

Recreational activities in the mountains include winter snow sports, notably at Baw Baw and Hotham, road touring, fishing, bush-walking and related activities in the warmer months. In the foothills and on the plains, parks are popular but most recreational activity is based on the Gippsland Lakes and, to a lesser extent, on Lake Glenmaggie and the ocean beaches. The sheltered lakes are favoured for all forms of water-based sport.

Residential use

Population centres with developing secondary industry, notably Moe, Morwell, Traralgon and Sale, are growing rapidly. Other inland towns which are supported largely by primary industry, are expanding more slowly. The historic inland township of Walhalla as well as town and camping parks along the ocean and lake shore have economies based mainly on tourism. The larger resort centre are Seaspray, Paynesville, Raymond Island, Metung and Lakes Entrance.

Extensive areas have been subdivided for holiday homes, notably on the dunes and marine terraces between Seaspray and Paradise Beach, at Lock Sport and the Banksia Peninsula, and near the Tambo River mouth.

Mining

The main deposits for extractive industries are brown coal, sand, and gravel and limestone. The Gippsland Sedimentary Basin contains the offshore oil and gas fields and about 95 per cent of

Victoria's deposits of brown coal. The brown coal, in thick seams of Lower Tertiary age, is located mainly in the La Trobe Valley where it underlies an area from 10 to 30 km wide extending 70 km eastwards from Yallourn to the south of Sale. To date most of the brown coal is used for electricity generation. Towards the end of this century, however, when the oil fields near depletion, brown coal could supply a significant part of Australia's liquid petroleum needs, and later, when natural gas resources are low, could provide substitute gas. Access to brown coal deposits has been protected under local planning controls instituted by the relevant shires during the period March-June 1980.

Service easements for oil and gas pipelines cross the foredunes at several places and pass via Dutson to the Gas Processing and Crude Oil Stabilisation Plant at Longford. From Longford, pipelines carry gas for immediate use to Dandenong Sale, Maffra and Maryvale, and oil and gas for further processing to Westernport.

Large quantities of high grade building and road-making materials are available in Cainozoic sand and gravel deposits. Supplies are taken from many small pits. Older limestone deposits of Silurian and Devonian age e.g. at Bindi, could be mined as marble. Tertiary limestones which are relatively impure, are suitable for cement crop on the sides of major valleys in the lowlands, and are easily worked.

Water production

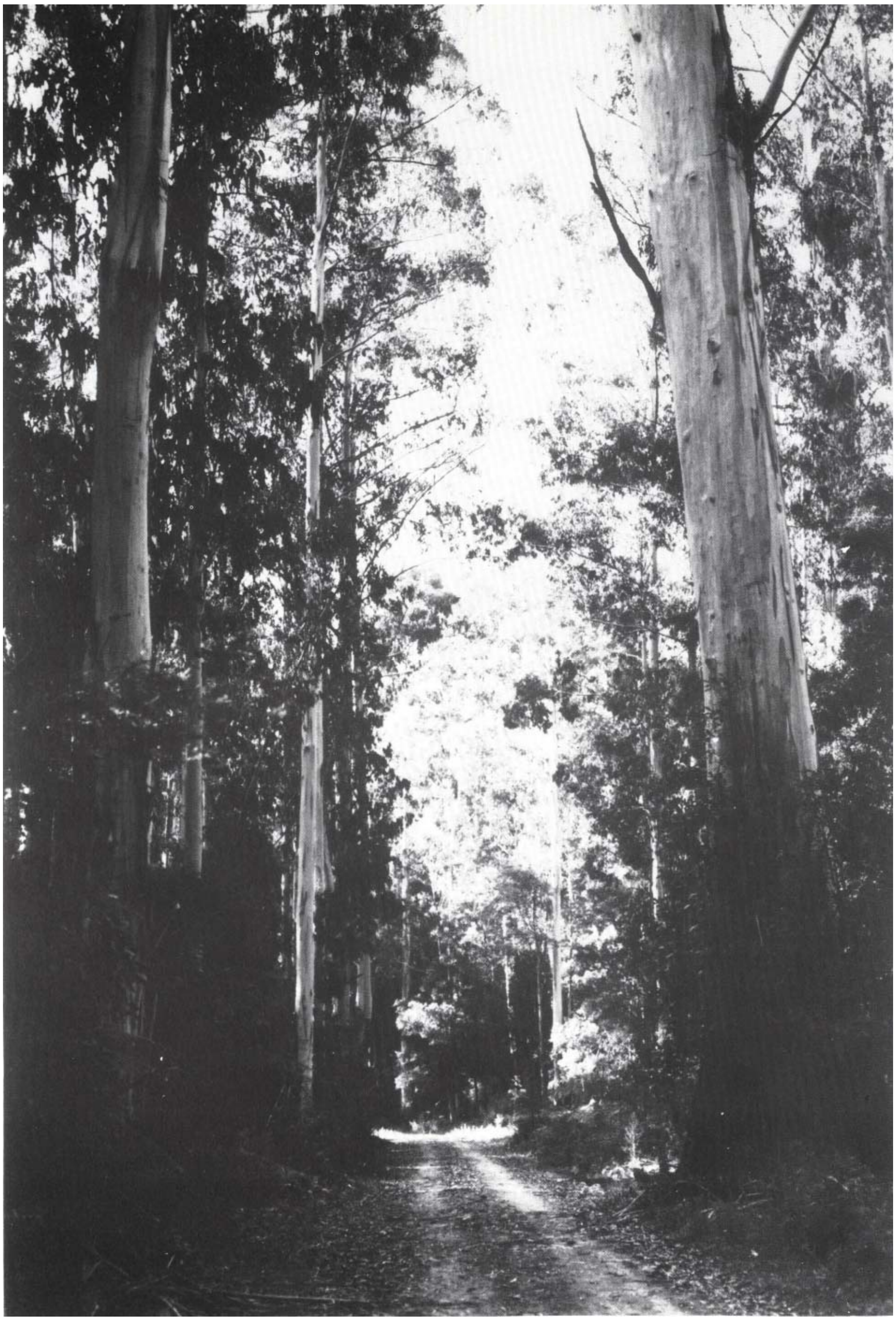
The large water resources of the region are used for supplying Melbourne, and locally for domestic and stock consumption, irrigation, industrial use, for example the power stations of the Yallourn Valley, and to maintain the health and viability of the Gippsland Lakes. Projected future increases in water consumption could significantly reduce stream flows, particularly those entering Lake Wellington. This could result in increased salinity in the Lakes and increased concentrations of nutrients and other pollutants. Also, a reduction in the water levels of swamps could result in a reduced bird population.

The main centres of population are largely supplied by water pumped from the rivers, but Sales water is obtained from bores. Most farmers rely on rain-water tanks and earthen storages although some of these storages are connected to town water. Around Dutson and in the catchments or Merriman Creek below Stradbroke, Carr Creek and Tom Creek, many of the landholders depend largely on bore water.

Grazing is one of the major land uses n the lowlands.

Native forests in the mountains are a major source of hardwood timber.

The alluvial terraces are often cultivated for vegetable growing.



The majestic mountain forest not only provides attractive scenery, but also important wildlife habitats and water catchment protection.

7. LAND CLASSIFICATION

Concept

In general purpose land resource surveys definition of classificatory units is based on the ecosystem concept in which several land characteristics are considered. Those generally used are climate, lithology, landform, soil and native vegetation, which interact to affect the inherent properties and processes of the land.

In general concept, a classificatory unit can be considered as an area of land with specified variation in the five features listed above and therefore having a specified range of properties and processes significant for a variety of uses and levels of management in terms of productivity and susceptibility to land deterioration.

Mapping is required at various scales, ranging from a few hectares to the whole State, to meet planning needs/ Consequently four categories of classificatory units are used-simple land component, complex land component, land system and land zone. These are defined in table 7.1.

Variability of landscapes precludes the setting of rigid scales for these units. For example, land systems are commonly mapped at scales of 1:100, 000 to 1: 250, 000 but occasionally at 1:50, 000 or 1:500,000.

The units are described in terms of the condition of the land before intensive modification, which began in the mid-nineteenth century and subsequently extended to a large proportion of the State. Description of the original condition requires observations on relatively undisturbed sites and the lack of such sites leads to inadequate data in some intensively-used districts. Knowledge of the undisturbed condition provides a standard against which to compare the effects of uses on the land and vice versa.

In this survey the land has been classified into land systems and simple and complex land components, though only the land systems are mapped. The definition in table 7.1 were not available at the start of this survey and hence they should be regarded as a general guide only. In this report, land systems are grouped into geomorphic provinces defined in terms of modern landscape dynamics (Aldrick *et al* 1978) rather than into land zones based on the purely morphological approach.

Table 7.1 - Definition of classificatory units used in general purpose land resource surveys

Land component – land distinguished by it s narrow range of geological material, landform, soil and native vegetation. These features are uniform at he detailed levels of classification shown below;

A complex land component has obvious variation in one or more of the features, but at a scale considered too complex to map in detailed surveys.

Land system – land distinguished by its range of geological material, landform, soil and native vegetation in which the variation, although usually substantial, can be expressed as a repetitive sequence of particular land components.

Land Zone – land consisting of land systems that are related in terms of one or more of the less dependent land features – landform, geological material and climate. Soils and native vegetation are listed in broad terms but differences in these dependent features are not diagnostic.

Classificatory level for land features in the various classificatory units

Classificatory Unit	Landform	Lithology	Soil	Native Vegetation
Simple land component	Landform Element	Lithological type	Principal PF	Association and Formation
Complex land component	Landform Element	Uniform or varied Texture, Structure, genesis	Principal PF(s) Primary PF(s)	Association (s) And formation(s)
Land system	Landform Pattern	Varied texture, Structure, genesis	Principal PFs Primary PFs	Associations and formations
Land zone	Landform Pattern	Dominant texture, Structure, genesis	Primary PFs	Formation (s)

Methods of classifying landform, lithology, soil and native vegetation are those of the Australian Soil and Land Survey Field Handbook (McDonald *et al* 1984). Climate is used as a differentia for land zone only.

Land Classification and Survey Methods

Land Classification

The initial stage of classification

Initial subdivision o the study area was into Uplands and Lowlands on the basis of elevation and age of parent materials, as described in the geomorphology chapter.

Land within the Uplands was classified into three broad groups and these were subdivided according to selected characteristics.

1. Terrain with entrenching streams below the lower snow-gum line

Most significant variations in this land were considered to be related to variations in topography, lithology, and vegetation type representing a rainfall-vegetation-elevation complex. Appropriate classes were developed for each of these characteristics (Table 7.2). Two vegetation types were recognized. Humid forests had vigorous tree and understorey growth, often non-sclerophyllous species, rotting logs, and significant species diversity including fungi, mosses and lichens. The drier forests were less vigorous, less diverse, usually with sclerophyllous species, with fungi and mosses not in evidence.

2. Land with entrenching streams above the lower snow-gum line – alpine and sub-alpine zones

In this study the sub-alpine zone is taken to the terrain with *E. pauciflora* forests and woodlands; the treeless areas above this are regarded as alpine.

At elevations above the lower limit of snow-gums, the influence of lithology on the vegetation seemed much reduced. With respect to climate, temperature effects appeared to be greater than those of rainfall.

Treeless areas within the sub-alpine zone were observed in two distinct topographic positions, one being on convex slopes at high elevations where narrow linear treeless corridors radiate downslope. Association summits often have alpine climates and are thus also treeless. The lack of trees in these corridors is ascribed in inhibition of tree growth by low temperature, possibly promoted by downslope movement of cold water, especially snow-melt water. The second occurrence is on relatively gentle slopes which previously has lacustrine or paludal conditions, such as occur on the valley-fill volcanic plains. Treelessness is associated with various factors, such as water-logging, cold air drainage and frost.

The initial emphasis in subdividing the land was on topography and ecology. Only three lithological categories were recognized.

3. Prior land surface residuals

Prior land surface residuals occur mainly below the lower snow-gum line. The effects of the current wave of stream entrenchment, which began after the Plio-Pleistocene Kosciusko uplift, have been relatively small in these areas so that the topography remains similar to that of the earlier surfaces. Subdivision was initially based upon topography and vegetation type, representing a rainfall-vegetation-elevation complex.

Table 7.2 - Characteristics used to subdivide the Uplands into land systems

1. Terrain below the low snow0gum line with active stream entrenchment

Topography
- precipitous slopes and cliffs
- mountainous terrain, ridge-and-ravine topography
- hilly terrain, ridge-and-ravine topography
- low hills and undulating terrain

Lithology
- ultrabasic volcanics
- basic volcanics
- acid volcanics
- plutonic rocks and high grade metamorphic (gneisses)
- Ordovician, Silurian and Devonian sediments (no marked hardness variation)
- Carboniferous sediments (alternating hard and soft strata)
- Calcareous sediments
- Cretaceous sediments
- Tertiary sediments

Vegetation type
- humid forests
- drier forests

2. Land above the lower snow-gum line with active stream entrenchment

Topography
- steep slopes, ridge-and ravine topography
- undulating to hilly plateaux

Lithology
- older volcanics
- strongly jointed igneous and metamorphic rocks
- other lithologies

Ecology
- the presence of open plains; treelessness associated with low temperatures
- the presence of plains of lacustrine origin, treeless or timbered

3. Prior land surface residuals

Topography
- hilly or sloping terrain
- low hills to undulating terrain

Vegetation type
- humid forests
- drier forests

These groups are summarized below

Subdivision of the Lowlands into land systems was based on geomorphic history. Distinct units can be recognized on the basalt flows and various sedimentary deposits such as the Tertiary outwash fans, alluvial plains and terraces, Aeolian sand deposits and coastal barrier systems. This is dealt with in detail in the discussion of the geomorphology of the Lowlands in Chapter 3. Land system boundaries were drawn on 1:80, 000 black and white aerial photographs using photo patterns, Land-sat imagery and geological maps to identify variation in topography, vegetation and geology. Many boundaries occur on distinct changes in landform, parent material or vegetation but where the change was gradual, boundaries were placed where they were considered most relevant to land processes.

The geological maps used were those prepared by the Victorian Geological Survey (1971-1977). Landsat imagery used included a computer enhanced false colour composite at 1:250, 000 scale and 20 x 20 cm prints of various spectral bands

Field checking and data collection

A program of field work was undertaken to check the preliminary aerial photograph interpretation and to obtain data on the land characteristics.

The survey area was systematically traversed between late 1978 and mid 1980. Sites were selected which were regarded as being representative of the characteristic photo patterns. Approximately eight hundred sites were visited and at each of these, topography, soils and vegetation were described. Data relating to landscape dynamics and stability were gathered where possible and observations of roadside cuttings and other features were made during traverses. Soil samples from seventy representative soil profiles were collected for chemical and physical analysis. Descriptions of these profiles and the laboratory analyses are given in Appendix 1.

Amalgamation of land systems into geomorphic provinces

As field work progressed, the desirability of greater emphasis on geomorphic processes became apparent, resulting in alteration to classification at the broadest scale. Geomorphic provinces and sub-provinces were recognized on the basis of current landscape-forming processes with less emphasis on morphology *per se*. Inclusion of process information provides a means of predicting responses of the land to a variety of disturbances – landscape-forming processes are fundamental to this. Chapter 3 provides a discussion of the concept and definitions of the various provinces.

The relationships between the geomorphic provinces, the land systems and their diagnostic characteristics are shown in the table on the back of the land system map.

The land system map

Land system boundaries were transferred from the aerial photographs to 1: 1000, 000 planimetric transparencies with 1: 100, 000 National Map bases. The coloured 1: 250, 000 land system map accompanying this report was obtained by reduction of the 1: 100, 000 mapping. Uncoloured dye-lines of the more detailed 1: 100, 000 sheets are held by the Land Protection Division.

The colour grouping of land systems is based on the geomorphic provinces as shown in the legend.

The land system descriptions

The characteristics and diagnostic features of each land system are tabulated in Volume 2, along with a general description. Data on climate, geology, physiography and land use are general for each land system while properties of soils and native vegetation refer to each component. Also presented are photographs and locality maps, together with block and cross-sectional diagrams. Brief explanations of how the data were derived are presented in Appendix IV.

All components listed for a particular land system may not be present in all localities, particularly in small occurrences.

Data on the susceptibility of each land component of deterioration following disturbance are also given with the land system descriptions, allowing predictions to be made about responses of the land to various land uses. (For a fuller discussion of susceptibility to deterioration see Chapter 8).

Chapters on regional climate, geology and geomorphology, soils, native vegetation, present land use and soil conservation have also been prepared. The full benefit of the land system tables can only be obtained if those chapters are also referred to.

Precision limits of the land systems map and descriptions

The following points need to be considered when referring to the land system map and descriptions.

Variability within the land systems

It has not always been possible to describe the total variation in vegetation and soils within the components due to the problems of scale and expediency.

Land system boundaries

Most changes in land characteristics used to define the land systems were mapped according to air photo pattern. Consequently, some boundaries may not be accurate due to possible errors in photo-interpretation.

Areas of land system too small to be mapped at 1:100, 000 or 1:250, 000 scale are included within the surrounding land system. This may be mentioned in the general description of a land system. For example, in many of the land systems with ridge and ravine topography, the occurrence of unmappable alluvium similar to that in Walnut land system is noted.

Correlation with Previous Land System Mapping

Three land system and reports (Rowe and Downes 1960; Sibley 1975; Nicholson 1978) occur within the Gippsland Lakes Catchments.

Difference in mapping are due partly to changes in mapping criteria, and partly to the availability of more detailed and accurate geological maps since the earliest reports were published.

Nicholson's map is based mostly on land morphology and the pattern of repetitive landform sequences whilst greater emphasis has been placed in this report on genesis, dissection and erosion of landforms and occasionally on soil parent materials. Sibley's Baw Baw land system is almost identical with the Baw Baw of this report. The Glenmaggie, Macalister and Wellington land systems of Rowe and Downes have been defined on different characteristics from the land systems of the same name in this survey.

8. SOIL CONSERVATION

Introduction

Soil conservation is achieved when the management of land maintains or improves the stability and productivity of the soil. Accelerated soul loss may be the detriment of not only the eroded land but also the adjacent lands, waters and other resources. In order to achieve soil conservation, we need to understand the inherent characteristics and processes in land and the way these influence the potential for both production and deterioration. The effects o these characteristics and processes of specific use-management regimes also need to be understood (Rowe *et al* 1981).

The previous chapters have outlined relevant characteristics and processes in lands of the study area. The emphasis in this chapter is on (1) defining types of soil deterioration and their predisposing environment factors; (2) distinguishing the processes which lead to each form of deterioration and the disturbances which produce them, and (3) evaluating the inherent susceptibility of the various land types of these processes. The evaluation is relevant to uses in general, being related to broad categories of disturbance rather than specific uses. However, these broad categories of disturbance can be related to individual land use practices. This chapter also contains comments on the observed incidence of deterioration and the associated activities.

Soil deterioration

Natural processes are responsible for the gradual evolution of the land's characteristics. In using the land, man alters these processes and initiates ones new to a site. The effect upon the land may be one of deterioration, no change, or improvement, depending on the disturbance created and the processes affected, and on the characteristics of the land.

In assessing the effects of disturbance, a standard condition of the land is taken as frame of reference. This is the relatively undisturbed condition which can be observed in most districts, for example, on roadsides or other reserves.

The distinction between deterioration and inherent limitations of the land

Inherent characteristics and processes in the land may be limiting for some forms of use; for example, extensive rock outcrop or poor drainage may limit agricultural use. Some characteristics may be critical for particular forms of use but not others. Thus mountain slopes may be acceptable for forestry but not for agricultural crops.

Data on characteristics that may be limiting are given in the tabular land system descriptions of volume 2. these include estimates of degree of slope, rockiness, soil depth, drainage, nutrient status and available water capacity. Although some of these characteristics may be seen as adverse from a productivity point of view, they should not be construed as soil deterioration.

Forms of deterioration

There are many forms of soil deterioration, differing on the basis of mechanisms and soil properties affected. Definitions of forms are given at the end of this chapter, along with predisposing land properties. These definitions have been restricted to the major forms of deterioration recognized within the catchments, viz, sheet and rill, gully, scour, tunnel, streambank, wave and wind erosion; mass movement by soil creep, solifluction and landslip; nutrient loss; structure decline; water-logging and salting.

Assessment of the Susceptibility of the Land Forms of Deterioration

The susceptibility of an area of land to a particular form of deterioration is related to the ease with which the associated processes can occur; it is related to the inherent properties of the land in question and is considered independently of land uses and severity of disturbance. For example, soil loss by sheet erosion involves particle detachment and transport by rain splash and surface flow. The susceptibility of the land to soil loss is therefore related to the land properties which influence resistance of the soil particles of detachment and transport, such as the size and weight of soil particles and their cohesion, and the volume and velocity of surface flows. Generation of surface flows is influenced by such factors as infiltration capacity of the topsoil, profile permeability and water holding capacity, slope of the land and rainfall intensity.

It is important that the concept of susceptibility to deterioration be distinguished from the concepts of magnitude of deterioration, tolerance of deterioration, and hazard of deterioration.

The magnitude of a form of deterioration involves amount and areal extent; for example, the amount of soil lost or the area of land waterlogged. It is determined by the severity and type of land disturbance as well as the inherent susceptibility of the land.

The tolerance of the land to deterioration relates to the effects of deterioration on productivity.

The hazard of deterioration involves the probability of deterioration occurring; this depends on land use and management, the magnitude and areal extent of disturbance and susceptibility.

The land susceptibility tables

The susceptibility of the components in each land system to various forms of soil deterioration is considered in the land susceptibility tables in volume 2.

As well as providing an assessment of inherent susceptibilities, these tables indicate processes to which the particular forms of deterioration are related, the direction of change in the process which will result in deterioration and categories of disturbance that will produce this change.

The concepts involved in these tables are discussed below under the headings which appear in the tables, namely category of disturbance, affected process and trend, primary resultant deterioration, primary off-site process and the incidence of deterioration.

Category of disturbance

In assessments of land capability for specific uses management practices and other variables are specifies, but in multi-purpose land system surveys, the data must cater for a variety of uses in a time-independent framework, and use/management categories are not appropriate.

For this reason, categories of disturbance, rather than specific use-management regimes, have been associated with different forms of deterioration; these define the broad type of disturbance which alters those processes producing the described form of deterioration. These categories are almost independent of both form of land use and level of management, in that various types of use or management could produce the same impact upon the land. As an example, reduction in leaf area could be caused by clearing, logging, ringbarking, fire, overgrazing or insect attack.

Besides removing the need to specify land use and management practices, another advantage of using categories of disturbance is that the aspect of land use or management which produces a particular form of deterioration is made explicit. This is particularly useful when a use/management combination, such as heavy grazing, involves several types of disturbance such as reduced leaf area, increased exposure of surface soil and increased physical pressure on the soil. The system also enables any potential land use to be considered.

Four broad categories of disturbance, with examples of practices which may cause them and responses that could follow, are given below.

1. Alteration of vegetation: reduction on leaf area, perenniality or rooting depth.

This type of disturbance can be caused by practices such as clearing, cultivating, selective logging, ringbarking, grazing or fire. The usual result is a reduction in the amount of water removed from the regolith by transpiration. Responses of the land will vary with land type, and may include greater deep percolation and leaching resulting in nutrient loss, increased accumulation of soil water and rising water tables, landslides and off-site effects such as seepage, salting and raised baseflow in streams.

2. Increased exposure of surface soil

The soil surface is protected by living plants, organic litter, stumps, logs and other debris, and stone lags or pavements. Disturbance of these protective covers can be caused by fire, clearing, grazing, cultivation, and access to the soil surface, leading to various forms of soil erosion and off-site accumulation of silt; infiltration of water into the soil is also often reduced due to surface sealing by rainfall.

3. Increased physical pressure on soil

compaction is caused by increased trafficking or trampling of the soil surface by animals, humans, dragged logs, vehicles such as four wheel drives, trail bikes, tractors and bulldozers, and by machinery such as ploughs. Decreased macroporosity will usually result in decreased infiltration and increased run-off, affecting the quality and regulation of streams.

4. Increased soil disruption

Many activities result in physical soil disruption, for example clearing, logging, cultivating, stock trafficking, roading and other engineering works. Burrowing by animals, particularly rabbits may have a similar effect. The main primary responses of the land are erosion, off-site siltation and water pollution.

Other categories of disturbance occur, such as direct alteration f the water regime, but these localized disturbances are not included here. Examples of disturbances which directly alter the water regime are the application of irrigation water and the storage of water in dams. The opening of an artificial entrance from a lake to the sea is an unusual type of disturbance which affects some land systems.

Affected process and trend

In the tables it is practicable to list only the primary process responses to a particular disturbance, However, it should be understood that this primary response may activate a complex series of process changes, depending largely on land type. Chain reactions are common, for example, alteration of vegetation may result progressively in reduction of biomass, reduced incorporation of organic matter into soil, structure decline, increased run-off, decreased soil water content and further reduction in biomass. Chain reactions are particularly liable to occur when hydrological processes are altered and under these circumstances off-site deterioration can be expected, with ramifications further down the catchment.

A disturbance usually modifies existing processes, but processes new to the site can be introduced.

In this report the processes affected by a type of disturbance and the form of resultant deterioration have mostly been established through a combination of observation and deduction. Observations of deterioration both within and outside the Gippsland Lakes Catchments, however, were also used to verify and establish disturbance-process-response relationships.

Primary resultant deterioration: Form

The form of potential deterioration can be predicted from an understanding of the alteration to processes caused by disturbance and the characteristics of a land type.

A wide range of forms of deterioration, many of which already occur in the study area, are considered. Flooding, water table rises, stream water quality decline, altered flow regimes and stream course changes are considered in addition to the forms of deterioration listed at the end of the chapter.

As with processes, only the primary form of deterioration is given here, although it should be noted that other forms of deterioration are likely to follow.

Primary resultant deterioration: Susceptibility

Assessments of the susceptibility of the land to soil deterioration processes are very difficult to make because process-response systems in land are complex and difficult to study. However the processes involved in some forms of deterioration are well known and the influence of some land characteristics have been identified. In these instances, susceptibility has been based on the values of relevant land characteristics. These assessments are to a certain extent subjective and so the class intervals which have been used are broad: very low, low, moderate and high. The value of such ratings is relative rather than absolute. Wherever possible, observations of deterioration in relation to degree of disturbance have also been used to assess susceptibility.

Primary resultant off-site process

Altered processes at a site may lead to deterioration elsewhere. For example, increased run-off from a compacted soil on a hill-slope will increase run-on at lower sites, and may lead to gullying or siltation of drainage floors.

Water movements play a large part in off-site effects, either by physically moving sediments and salts, stimulating landslides, or by direct alterations in water volume, velocity, peak-to-mean discharge ration, and direction of flow.

The incidence of land deterioration

The incidence of deterioration observed in each land system during the survey, along with the associated land uses, is noted at the foot of each table. The observed incidence is the visible manifestation of the interaction between the inherent susceptibility and the nature, areal extent and intensity of disturbance; it provides a guide to the extent of deterioration likely in a given land type under a particular type of management. It should be kept in mind that:

(i) if no deterioration was observed during fieldwork, it does not signify that none exists in the mapping unit, although in these cases it is likely to be rare, and
(ii) the absences of a form of deterioration does not necessarily indicate that the susceptibility of the land system is negligible. It may only indicate that there has been no disturbance severe enough to set degradation in motion.

Precision limits of land susceptibility tables

The disturbance-process-from of deterioration sequence shown in tabular form for each land system is designed to foster an understanding of the way deterioration is brought about and so to evaluate the effects of various uses and management practices and other activities. It is important, however, that the tables are not used beyond the purposes for which they were designed. In this context, the following points need to be considered.

Degree or extent of deterioration

Ratings of the inherent susceptibility of the land to particular process-response relationships do not give direct measure of the degree or extent of deterioration which will occur if the disturbance involved takes place. Susceptibility is but one factor, others being the extent and degree of disturbance and any corrective management inputs.

The significance of land deterioration

The ratings of the relative ease or rapidity with which the land will undergo each particular type of deterioration give no indication of the significance of this deterioration. For example, a soil which is rated as having a low susceptibility to sheet erosion may be shallow, and soil loss, even though sloe, would remove a significant proportion of that soil.

Variability in susceptibility within land systems and components

Land types within the catchments have been classified on the basis of similarity in process and form, so that the effect of disturbances on process should be relatively similar within any one land system component. There will, however, be local variations in susceptibility within the component due to inevitable variations in land features, such as soil texture and slope.

Process of Soil Deterioration – Definitions and Land Characteristics Involved

The predominant types of soil deterioration recognized in the catchments of the Gippsland Lakes are briefly defined below. The definitions are followed by a discussion and/or tabular summary of the land characteristics involved.

Sheet (inter-rill) and rill erosion

Sheet erosion is the removal of relatively even layers of soil from the land surface, resulting primarily form the effects of raindrop impact and the transport of detached soil particles by splash and thin-film run-off. It occurs after the protective cover of plants and litter has been reduced, exposing the soil surface. Rill erosion is the removal of soil within small channels where run-off water concentrates and develops sufficient velocity and turbulence to detach soil by hydraulic shear. Rills are channels which can be obliterated by tillage. These forms are summarized by Fairbridge and Finkl (1979).

Sheet and rill erosion are considered together because run-off usually does not take place as thin-film flow for great distances, but tends to channelise due to irregularities in the shape and nature of soil surface. Thus sheet and rill erosion tend to be inextricably interwoven.

Land characteristics; See table 8.1

Gully and tunnel erosion

Gully erosion results to channels too large to be readily obliterated by tillage. In practical terms, channels with a depth of 0.5 m or more are considered gullies.

In Victoria, Milton (1971) classified gullies on the basis of formative mechanisms e.g scouring, sapping, spalling, slumping. Sargeant (unpublished report) describes the different forms of gully heads and walls and discusses the relevant detachment and transport processes.

Tunnel erosion is the removal of soil from subsurface seepage flow paths. The formation of tunnels has been described by Downes (1946) and Crouch (1980). It occurs when run-off is generated on a soil surface with a low infiltration rate and with interconnected cracks and other holes, such as old root channels and burrow. The water moves preferentially along these cracks and other voids in the subsoil, removing soil. As the tunnels enlarge the ceilings may collapse to form gullies.

Land characteristics; See table 8.2

Comments:
(i) lack of cohesion between particles is characteristic of soils with high sand and silt content and not cemented by agents such as carbonates, iron oxides or organic matter and of loose gravelly detrital materials with a fine earth matrix.
(ii) Cracks and channels develop in soils with a high shrink-swell capacity;

Scour erosion

Scour erosion refers here to detachment and removal of soil by flood waters beside the main rivers and creeks.

Land characteristics

The erosivity of the floodwaters depends on the volume and velocity of their flow. This is determined by:

(i) rainfall intensity and duration in the catchment
(ii) catchment area and topography
(iii) infiltration and water-holding capacities of soils in the catchment
(iv) stream channel size
(v) the gradient and microrelief of the flooded land

The soil characteristics influencing susceptibility are the same as those involved in the other forms of water erosion.

Streambank erosion

Streambank erosion is the collapse of streambanks usually cause by under-cutting of the banks by the stream. It is often exacerbated by stock, people or vehicles and tree clearing along streams.

Bank erosion occurs along river channels cur into alluvium, particularly in meandering river systems. It is accelerated when the flow regime of a river is altered due to changes in the catchment, such as clearings, which increase the frequency and volume of peak flows. Straightening of stream channels also leads to more violent velocities and decreased channel storage.

Land characteristics; See table 8.3;

Wave erosion

Wave erosion is the removal of material from lake and sea shores by waves.

Wave erosion often occurs along undisturbed shores but it can also be initiated or exacerbated by man-induced changes of lands and waters. Any change which increases the energy with which waves arrive on shore will increase wave erosion. Waves of greater energy penetrate further inland and remove more material with backwash.

Land characteristics

Susceptibility of a shore to wave erosion appears to be affected by the degree of cohesiveness of the soil particles and their size, smaller particles being more easily removed. A mat of fine roots will provide some protection. Other factors are aspect in relation to prevailing strong winds, the fetch of water and the depth of water off-shore. In the survey area, western aspects of lake shores are most vulnerable.

Wind erosion

Removal of soil by wind takes place when wind velocities are sufficient to lift and transport unattached particles. Fine particles can travel great distances as dust but coarser and heavier particles move by saltation and creep over the ground surface; the size and weight of particles that can be transported depends on wind speed.

Land characteristics; See table 8.4.

Comment: soil with high organic matter content, such as peat or Alpine Humus soils, tend to have low specific gravity.

Mass movement – soil creep and landslide

Soil creep is the imperceptibly slow by significant downslope movement of a mass of soil; it does not require saturated conditions.

Landslides are sudden movements of soil or rock masses down a slope.

Landslides (earth and mudflow) leave characteristic concave hallows with crescentic upper edges, whilst at their vase the displaced material often has an irregular surface.

Land characteristics; See table 8.5 and 8.6

Nutrient loss

Nutrient loss is defined here as the loss of nutrients, principally cations, from the soil. Other nutrient problems, such as toxicities associated with altered soil pH, are not included.

Nutrients are held within the vegetation, soil and underlying rock, and accessions occur from the atmosphere; not all of these reserves are available to plants although they may become so after decomposition and dissolution of the organic or inorganic material in which they are held. Any loss of nutrient from this store of potential plant losses of nutrients can be considered deleterious. The most rapid losses of nutrients result from the removal of vegetation or from burning and the loss of nutrients in smoke or in ash eroded from the site.

The concept of susceptibility is based on the ease with which available nutrients are removed from the soil, and although this can occur via various mechanisms, the one that is considered here is leaching by percolating water. Soils with low cation exchange capacity and high permeability are particularly prone to nutrient loss by this mechanism. Sands with low organic matter contents are the most common soils with these properties.

Land characteristics; See table 8.7

Structure decline

Structure decline (or compaction) is a change in the arrangement of solid particles and intervening spaces which has deletrious consequences for plant growth, usually as a result of the effect on soil hydrological processes and on root development.

Soil structure is a term expressing the three-dimensional arrangement of primary soil particles. It includes the shape and size of any secondary units or aggregates as well as their distinctness. Structure influences the pattern and stability of pores and thus hydrological processes such as the infiltration of rain, the retention of water and the drainage of excess water. The pores are also vital to plant growth as they store available moisture and allow oxygen to enter the soil and carbon dioxide, produced by root respiration, to escape to the atmosphere. Pores also provide pathways for roots to grow. The arrangement of pores, aggregates and primary soil particles has to be strong enough to support its own mass and that of plants and animals living on its surface.

Structure decline occur when increased physical pressure and reduction of organic matter cause this three-dimensional arrangement of particles and voids to lose its mechanical strength and suffer a partial or total collapse. The result of such compaction is usually decreased infiltration, increased run-off and decreased aeration of the root zone.

Land characteristics; See table 8.8

Water-logging

Water-logging is the accumulation of water within the soil profile to such an extent that few air spaces remain. Reduced soil aeration reduces plant productivity except in species adapted to wet environments.

Conditions which favour water-logging include:

(i) land having a locally low position which receives run-on and seepage water
(ii) land with naturally high groundwater tables
(iii) gentle slopes which retard the dispersal of excess water
(iv) slowly permeable soil or rock layers

Salting

Salting is the concentration of soluble salts within the root zone to levels damaging to the growth of plants other than halophytes. Accepted threshold values for total soluble salts are 01. to 0.3% (Northcote and Skene 1972).

Salts that have accumulated in rocks, unconsolidated sediments and the regolith over time can be mobilized and moved upwards or laterally by groundwaters. There these waters approach the surface, the salts can be concentrated by evaporation.

Land characteristics, See table 8.9

Table 8.1 Land characteristics and management factors involved in sheet and rill erosion

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Sheet and rill erosion occur when the forces due to rainfall, flowing water and gravity overcome the cohesion and weight of the soil particles/aggregates	Vegetation -Structure, percent surface cover (including litter) -leaf area, rooting depth and perenniality	• Exposure to surface soil • Intensity of raindrop impact • Infiltration/run-off ratio • Velocity of surface flow • Transpiration and hence infiltration rate and volume of surface flow	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as: Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Processes involved are: Detachment of exposed soil by - raindrop impact - surface flow	Climate -rainfall intensity/duration -seasonal rainfall/evapotranspiration regime	• Intensity of raindrop impact • Volume of water exceeding infiltration rate and hence volume of surface flow • Soil water content and hence infiltration rate and volume of surface flow.	
Transport by -rain splash -surface flow	Geology -permeability of rock or unconsolidated sediments	• Soil water content and hence infiltration rate and volume of surface flow	
Deposition Surface flow occurs on any sloping surface when the rainfall rate exceeds the infiltration rate	Topography -microrelief -slope degree and length -slope and landform shape -position in landscape	• Infiltration/run-ff ratio • Velocity of surface flow • Volume and velocity of surface flow • Tendency to concentrate surface flow • Volume of run-on	Contour cultivation, contour banking and strip cropping reduce slope length and affect microrelief
Off-site effects include increased sedimentation and run-on in streams and on lower lands	Soil -profile permeability -depth and water-holding capacity -size/weight of surface particles/aggregates -cohesion of surface particles/aggregates, including tendency to slake and disperse -tendency to surface seal and hydrophobicity -percent of stone cover	• Infiltration rate and hence volume of surface flow • Infiltration/run-ff ratio • Detachment and transport • Detachment • Infiltration rate and hence volume of surface flow • Infiltration/run-off ratio and velocity of surface flow	The above management practices controlling biomass affect soil organic matter content, which in turn affects all listed soil characteristics except surface rock Direct soil compaction and disruption by trampling, trafficking and cultivation affect soil permeability, water-holding capacity and size/weight and cohesion of aggregates

Table 8.2 Land characteristics and management factors involved in gully and tunnel erosion

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Gully and tunnel erosion occur when the forces due to rainfall, flowing water and gravity overcome the cohesion and weight of the soil particle/aggregates	Vegetation -structure, percent surface cover (including litter) -leaf area, rooting depth and perenniality	• Exposure of surface soil • Intensity of raindrop impact • Velocity of channelised flow and hence particle detachment and transport • Transpiration and hence infiltration rate and volume of surface and subsurface flow	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Processes involved are: Detachment of exposed surface soil by -raindrop impact -channelised overland flow -cracking	Climate -rainfall intensity/duration -seasonal rainfall/evapotranspiration regime	• Intensity of raindrop impact • Volume of surface and sub-surface flow • Volume of surface and sub-surface flows via regulation of soil water content	
Detachment of subsoil by -subsurface flow in permeable strata and along cracks and tunnels -cracking	Geology -perviousness of rock or unconsolidated sediments	• Soil water content and hence infiltration rate and volume of surface and subsurface flow • Lateral or vertical movement of water	
Transport of particles/aggregates -channelised overland flow -subsurface flow -gravity collapse deposition Gully erosion is regarded as having occurred when the channel is too deep to be crossed or cannot be obliterated by tillage	Topography -microrelief (both of channel and catchment to a site) -channel slope degree and length -position in landscape and catchment area -catchment slope degree and length -slope and land-form shape Soil -profile permeability -depth and water-holding capacity	• Infiltration/run/off ratio • Velocity of surface flow • Infiltration/run-off ratio • Velocity of surface flow • Volume of surface and subsurface flows reaching site • Velocity of surface flow • Tendency to concentrate surface flow • Infiltration rate and hence volume of surface and subsurface flow • Lateral or vertical movement of soil water • volume of surface and subsurface flow	Contour and diversion banking, strip cropping and contour cultivating reduce catchment slope length and catchment area; they also affect microrelief Contour and diversion banking, strip cropping and contour cultivating reduce catchment slope length and catchment area; they also affect microrelief type amount of biomass production will affect soil organic matter content, which will in turn affect most listed soil characteristics Soil disruption and compaction by trampling, burrowing, cultivation
	-size/weight of soil particles/aggregates -cohesion of particles/aggregates, including tendency to crack, slake and disperse -differential permeability within a horizon due to the presence of cracks and channels -percent stone cover	• Detachment and transport • Detachment • Movement of water along preferred channels • Volume of surface flow	and trafficking will affect profile permeability, water-holding capacity and size/weight and cohesion of soil particles/aggregates

Table 8.3 Land characteristics and management factors involved in stream-bank erosion

<table>
<tr><th>Processes</th><th>Land Characteristics affecting processes</th><th>Factors affected by land characteristics</th><th>Management factors that modify land characteristics</th></tr>
<tr><td rowspan="5">Stream-Bank erosion occurs when forces due to water movement along a stream channel are sufficient to detach and remove soil material from the stream-bank

Processes involved are:
Detachment of soil from stream-bank by
- slaking
- undercutting
- collapse of bank

Transport by channel flow

deposition</td><td>Vegetation
- structure, percent surface cover (including litter)
- leaf area, rooting depth and perenniality</td><td>• Streambank stability

• Transpiration and hence infiltration rate and volume of surface flow
• Volume and velocity of stream flow</td><td>All aspects of the vegetation are affected by selection of species and control of biomass by particles such as
Cultivation Clearing
Trafficking Fertilising
Grazing Trampling
Harvesting Burning</td></tr>
<tr><td>Climate
- rainfall intensity/duration

- seasonal rainfall/evapotranspiration regime</td><td>• Volume of water exceeding infiltration rate and hence volume of surface flow
• Soil water content and hence infiltration rate and volume of surface flow</td><td></td></tr>
<tr><td>Geology
- permeability of rock or unconsolidated sediments in the catchment</td><td>• Soil water content and hence infiltration rate and volume of surface flow</td><td></td></tr>
<tr><td>Topography
- Slope, degree and length</td><td>• Volume and velocity of surface flow</td><td></td></tr>
<tr><td>Soil
- permeability of soils within the catchment
- soil depth and waterholding capacity
- cohesion of soil particles/aggregates including tendency to slake and disperse
- size</td><td>• Infiltration rate and hence volume of surface flow
• Infiltration/run-off ratio

• Detachment

• Detachment and transport</td><td>Contour cultivating, contour banking and strip cropping to reduce slope length

Restrict stream access by stock to less sensitive areas

Stabilise stream-banks with trees, shrubs and grasses</td></tr>
</table>

Table 8.4 Land characteristics and management factors involved in wind erosion

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Wind erosion occurs when the force due to wind is sufficient to overcome the cohesion and weight of the soil particles and to allow their movement	Vegetation - structure, percent surface cover (including litter) - leaf area, rooting depth and perenniality	• Exposure of surface soil • Depth of zero velocity layer • Transpiration and hence soil moisture content and particle cohesion	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Processes involved are:	Climate - rainfall/evapotranspiration regime - wind strength - wind direction	• Soil moisture content and hence particle cohesion • Detachment and transport • Site exposure	
Detachment by abrasion and suction	Geology - perviousness of rock or unconsolidated sediments	• Soil moisture content and hence particle cohesion	
Transport by creep, saltation and suspension	Topography - microrelief, slope degree and position in landscape	• surface wind strength • Run-on, site drainage and hence soil moisture content and particle cohesion	Retention or construction of windbreaks, cloddy cultivation and ridging affect microrelief
Deposition by entrapment and reduced wind velocity	Soil - percent stone cover - size/weight of surface particles/aggregates - aggregate stability (influenced by factors such as presence of carbonates, iron oxides and organic matter, clay mineralogy and biological activity) - profile permeability, depth and water-holding capacity	• surface wind strength • Detachment and transport • Detachment • Soil moisture content and hence particle cohesion and weight of particles/aggregates	Soil disturbances such as trampling, cultivating affect aggregate stability Any practices affecting biomass alter the organic matter content of the topsoil

Table 8.5 Land characteristics and management factors involved in soil creep

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Soil creep occurs when the decrease in soil strength resulting from an increase in soil moisture is sufficient to allow the imperceptible and non-accelerating movement of the soils mass	Vegetation - leaf area, rooting depth and perenniality - root depth and mass	• Transpiration and hence soil water content • Anchorage of soil by roots	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Processes involved are: Infiltration of rainwater	Climate - seasonal rainfall/evapotranspiration regime	• Soil water content	
Wetting of soil	Geology - perviousness of rock unconsolidated sediments	• Soil water content	
Soil movement by gravity	Topography - slope degree - microrelief and position in landscape	• Lateral gravitational component • Run-on, site drainage and hence soil water content	Earthworks, e.g terracing
	Soil - profile permeability - texture and structure - depth and waterholding capacity	• Infiltration • Soil water content • Soil strength • Soil water content	Compaction and soil disruption by stock and vehicles, and by cultivation will affect profile permeability and structure

Table 8.6 Land characteristics and management factors involved in landslides

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Landsliding occurs when the shear forces exceed soil/regolith strength: this generally occurs when soil regolith strength is reduced by an increase in water	Vegetation - leaf area, rooting depth perenniality - total leaf area and canopy type - root depth and mass	• Transpiration and hence soil water content • Volume of water held by canopy and hence volume available for infiltration • Anchorage of soil by roots	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Processes involved are:	Climate - seasonal rainfall/evapotranspiration regime	• Soil water content	
Infiltration of water Wetting of basal plane Saturation of soil (mudflow)	Geology - perviousness of rock or unconsolidated sediments - wet strength or rock/regolith - angle of dip	• Soil water content • Shearing tendency • Shearing tendency	
Shearing and movement of soil mass gravity	Topography - slope degree - microrelief and position in landscape	• Lateral gravitation component • Run-on, site drainage and hence soil water content	
Other processes that may be involved include: - loading of soil mass resulting in an increase I shear strength - removal of material from slope toe resulting in reduced slope support Types of landslides covered by this table are: - rock and earth slides - earth flow (downslope movement of unsaturated soil and weathered rock on a lubricated basal shear plane) - mudflow (movement of saturated soil and rock) - combination slide/flows	Soil - topsoil permeability - presence of slowly permeable layer - cohesion of particle/aggregates including tendency to slake and disperse - depth - clay mineralogy	• Infiltration/run-off ration • Water content of soil immediately above layer • soil strength • soil water content • Soil strength	Compaction and soil disruption by stock and vehicles, and cultivating, will affect profile permeability

Table 8.7 Land characteristics and management factors involved in leaching of nutrients

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Nutrient Loss involves the solution of cations and anions in water and their removal as the water percolates down through the soil	Vegetation - leaf area, rooting depth and perenniality	• Transpiration and hence soil water content and volume of percolating water	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
Leaching of nutrients is considered here in terms of base cations. The main anion involved in nitrate, the concentration of which fluctuates according to season and surface management, including the use of legumes	Climate - rainfall/evapotranspiration regime	• Volume of percolating water	
	Geology - permeability of rock or unconsolidated sediments	• Volume of percolating water	
	Topography - slope degree, microrelief, position in landscape and catchment are	• Run-on, site drainage and hence volume of percolating water	
	Soil - organic matter content - texture - clay mineralogy - water-holding capacity - profile permeability	• Cation exchange capacity (CEC) • CEC • CEC • infiltration/run-off ration • Volume of percolating water • Rate of water percolation	Control of biomass affects organic matter content water-holding capacity and profile permeability Cultivation and compaction by trampling and trafficking affect water-holding capacity and profile permeability

Table 8.8 Land characteristics and management factors involved in soil compaction

Processes	Land Characteristics affecting processes	Factors affected by land characteristics	Management factors that modify land characteristics
Compaction is the increase in soil bulk density and the related decrease in macroporosity that occurs when the physical pressure on the soil exceeds the ability of the soil to resist deformation and/or when organic matter is oxidised	Vegetation - leaf area, rooting depth and perenniality - structure and species accumulation	• Transpiration and hence soil moisture content and soil strength • Type and quantity of organic matter • Weight of plants • Root pressure on soil by growth and wind heave	All aspects of the vegetation are affected by selection of species and control of biomass by particles such as Cultivation Clearing Trafficking Fertilising Grazing Trampling Harvesting Burning
	Climate - rainfall/evapotranspiration regime	• Soil moisture content and hence soil strength	
Process involved is:	Geology - permeability of rock or unconsolidated sediments	• Soil moisture content and hence soil strength	
Closer packing of soil particles/aggregates	Topography - position in landscape, slope degree and microrelief	• Run-off, site drainage and hence soil moisture content and soil strength	Artificial drainage, contour banking, contour cultivation and strip cropping will affect soil moisture content
	Soil - texture and stone content - structure (dependent on factors such as clay% and mineralogy, carbonate, iron oxide and organic matter content and biological activity) - organic matter content - profile permeability, depth and water-holding capacity	• Soil strength • Minimum bulk volume attainable • Soil strength • Resilience to deformation • Soil moisture content and hence soil strength	Any practice that affects the vegetation will affect organic matter content Cultivating will increase oxidation of organic matter

Table 8.9 Land characteristics and management factors involved in salting

<table>
<tr><th>Processes</th><th>Land Characteristics affecting processes</th><th>Factors affected by land characteristics</th><th>Management factors that modify land characteristics</th></tr>
<tr><td rowspan="5">Salting occurs when stored salts derived from the atmosphere and from rock weather become concentrated in the root zone

Current accessions are insignificant compared with salt storage, except along coastlines or beside saline lakes and Salinas

Processes involved are:

Long-term accession of salts in regolith

Infiltration and percolation of rainwater

Leaching of salts to groundwater

Rise in water levels/pressure

Lateral transmission of water/pressure

Accumulation of salts within root zone by evapotranspiration in discharge areas

Off-site effects include increasing salinity of streams, groundwater and built storages

Pumping and drainage (mostly in irrigated areas) increase leaching of salts, reduce salt storage and lower groundwater levels/pressures, but disposal of extracted water and salts is a problem</td>
<td>Vegetation
- leaf area, rooting depth and perenniality</td>
<td>• Transpiration and hence volume of water percolating to groundwater</td>
<td>All aspects of the vegetation are affected by selection of species and control of biomass by particles such as
Cultivation Clearing
Trafficking Fertilising
Grazing Trampling
Harvesting Burning</td></tr>
<tr><td>Climate
- rainfall/evapotranspiration regime</td>
<td>• Volume of water percolating to groundwater
• Accumulation of salts within root zone</td>
<td>Irrigation increases water intake and hence the volume of water percolating to groundwater</td></tr>
<tr><td>Geology
- permeability of rocks and unconsolidated sediments
- clay content of rocks and sediments, often influenced by deep weathering
- geological structure and differential permeability of strata</td>
<td>• Leaching of salts

• Salt storage

• Lateral movement of groundwater
• Groundwater discharge
• Depth of groundwater
• Groundwater pressure</td>
<td></td></tr>
<tr><td>Topography
- slope degree
- change of slope
- local elevation
- position in landscape, slope degree and microrelief</td>
<td>• Lateral movement of groundwater
• site of discharge
• Depth to water table
• Run-on, site drainage and hence volume of infiltrating water</td>
<td>Contour banking and cultivating affect microrelief, increasing infiltration
Diversion banks reduce run-on and hence infiltration around discharge sites</td></tr>
<tr><td>Soil
- permeability

- water holding capacity

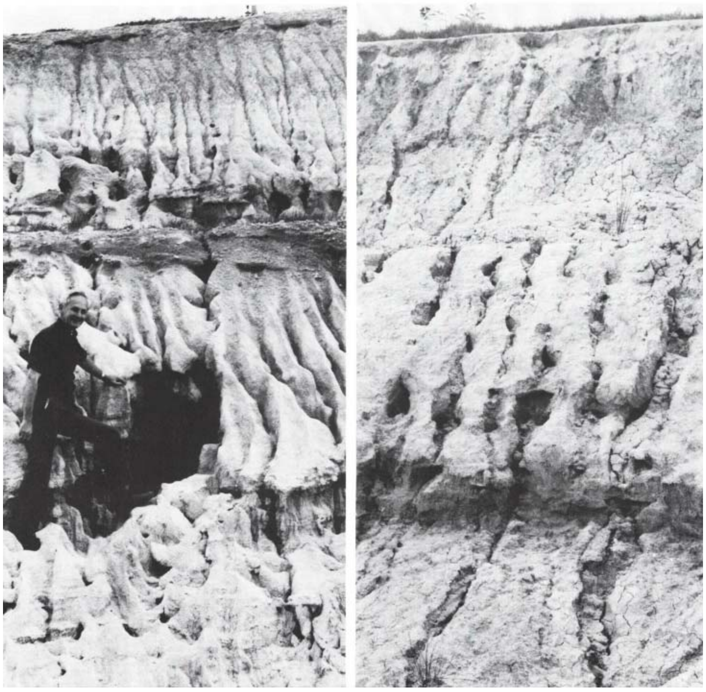
- depth and clay content
- microrelief</td>
<td>• volume of water percolating to groundwater
• Volume of water percolating to groundwater
• Salt storage
• Evaporation</td>
<td>Practices controlling biomass affect permeability, microporosity and water holding capacity directly or indirectly through effects on organic matter content</td></tr>
</table>

Mass movement – landslide and pronounced terracettes in Jeeralang land system

The steep slopes in Turton land system are susceptible to sheet erosion

Severe gully erosion in Gormandale land system

A relatively stable better in a Krasnozem where stability is enhanced by the soil's high infiltration capacity, rapid percolation and lack of dispersion



Rill and tunnel erosion in dispersive sediments on batters which face each other beside a road in Anderson 2 land system. The extent of erosion depends on siltation and associated volume of seepage – the more eroded batter receives seepage from upslope whereas the catchment is confined to the batter face on the opposite side.

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Glossary

Alluvial soil	A soil on young alluvium showing little horizon development
Anastomosing	Of streams, branching and rejoining irregularly to produce a net-like pattern
Antecedent river	A river which has cut through land that had risen in its path, and so maintained its course: so called because it is antecedent to the present topography
Anticline	A fold, the core of which contains the stratigraphically older rocks; it is convex upwards
Apedal	Soil material lacking peds, that is structural units
Association	A group of plant species; the definition used is that a Beadle and Costin (1952) – A climax community of which the dominant stratum has qualitatively uniform floristic composition and which exhibits a uniform structure as a whole
Avulsion	A sudden cutting off or separation of land by a flood or by an abrupt change in the course of a stream, as by a stream breaking through a meander or by a sudden change in current whereby the stream deserts its old channel for a new one
Backswamp	A swampy or marshy, depressed area developed on a flood plain with poor drainage due to the natural levees of the river
Base level	The theoretical limit or lowest level toward which erosion of the Earth's surface constantly progresses but seldom, if ever, reaches; especially the level below which a stream cannot erode its bed
Bases	The cations of the alkali metals and alkaline earths; the most common bases in soils are calcium, sodium, potassium and magnesium
Base saturation percentage	The extent to which the total cation-exchange capacity of soils occupied by cations other than hydrogen
Biomass	The quantity of material within the biotic component or the environment generally or within a specific component of the biota
Biodistribution	The overturning and/or mixing of soil materials by animals and plants
Bog	A wet area covered by acid peat
Clastic sediments	Sedimentary rocks which are produced from the disintegration of previous rocks through weathering processes and in the process of transportation the particle are graded, hence conglomerates, sandstones, siltstones and shales
Colluvium	A deposit of rock fragments and soil material accumulated at the base of steep slopes as a result of gravitational action
Consistence	Refers to the strength of cohesion and adhesion in soil
Corrosion	A process of erosion whereby rocks and soil are mechanically removed and worn away by the abrasive action of solid material moved along by wind, wave, running water and gravity
Diagenesis	Process involving the physical and chemical changes in sediments and rocks during metamorphism
Distributary	A branch or outlet which leaves a main river and does not rejoining it. It is usually applied to the numerous channels into which a river divides on its delta or fan
Epeirogeny	A form of diastrophism which has produced the larger features of the continents and oceans, e.g. plateaux and basins, in contrast to the more localized process of orogeny which has produced the mountain chains. Epeirogenic movements are primarily vertical, wither upward or downward, which have affected large parts of the continents
Epiphyte	A plant growing on, but not parasitic on, another plant
Fabric	Refers to the appearance of soil material, e.g. earthy, sandy, rough-ped or smooth-ped
Feldmark	A community of sub-glacial regions characterized by an incomplete cover of perennial evergreen dwarf shrubs and forbs
Forb	An herbaceous angiosperm which is not a grass
Forest (bed)	One of the inclined, internal and systematically arranged layers of a cross-bedded unit; specifically one of the gently inclined layers of sandy material deposited upon or along an advancing and relatively steep frontal slopes such as the lee side of a dune or outer margin of a delta
Glacio-eustatism	The worldwide change in sea level produced by the successive withdrawal and return of water to the oceans accompanying the formation and melting of ice sheets
Gleying	The process of weathering under reducing conditions due to saturation by water, tending to produce pale colours, often shades of blue, grey and green
Herb	Any vascular plant that is not woody
Hydrophyte	A plant that grows wholly or partly submerged in water
Interfluve	The area between rivers; especially the relatively undissected upland or ridge between two adjacent valleys containing streams flowing in the same general directions
Ions	Charged elements or compounds formed by the fain or loss of electrons; cations carry positive charges and anions negative charges

Liane	A non-paratic woody climbing or twining plant dependent for support on an established erect plant
Monocline	A unit of strata that dips from the horizontal in one direction only and is not part of an anticline or syncline. It is generally a large feature of gentle dip
Orogeny	An episode of tectonic activity (folding, faulting, thrusting) leading to mountain building
Paludal	Pertaining to a marsh
Periglacial	Peripheral to areas that are permanently snow-covered
Regolith	The unconsolidated mantle of weathered rock and soil material in the earth's surface
Seral stage	One vegetation type in the sequence of types that successively occupy a given area
Sesquioxides	The hydroxides of iron, aluminium, manganese and titanium
Texture	Field assessment of particle size distribution in soils e.g. sand, loam or clay