AGRICULTURAL AND HORTICULTURAL LAND SUITABILITY FOR THE WEST WIMMERA SHIRE

Volume 1

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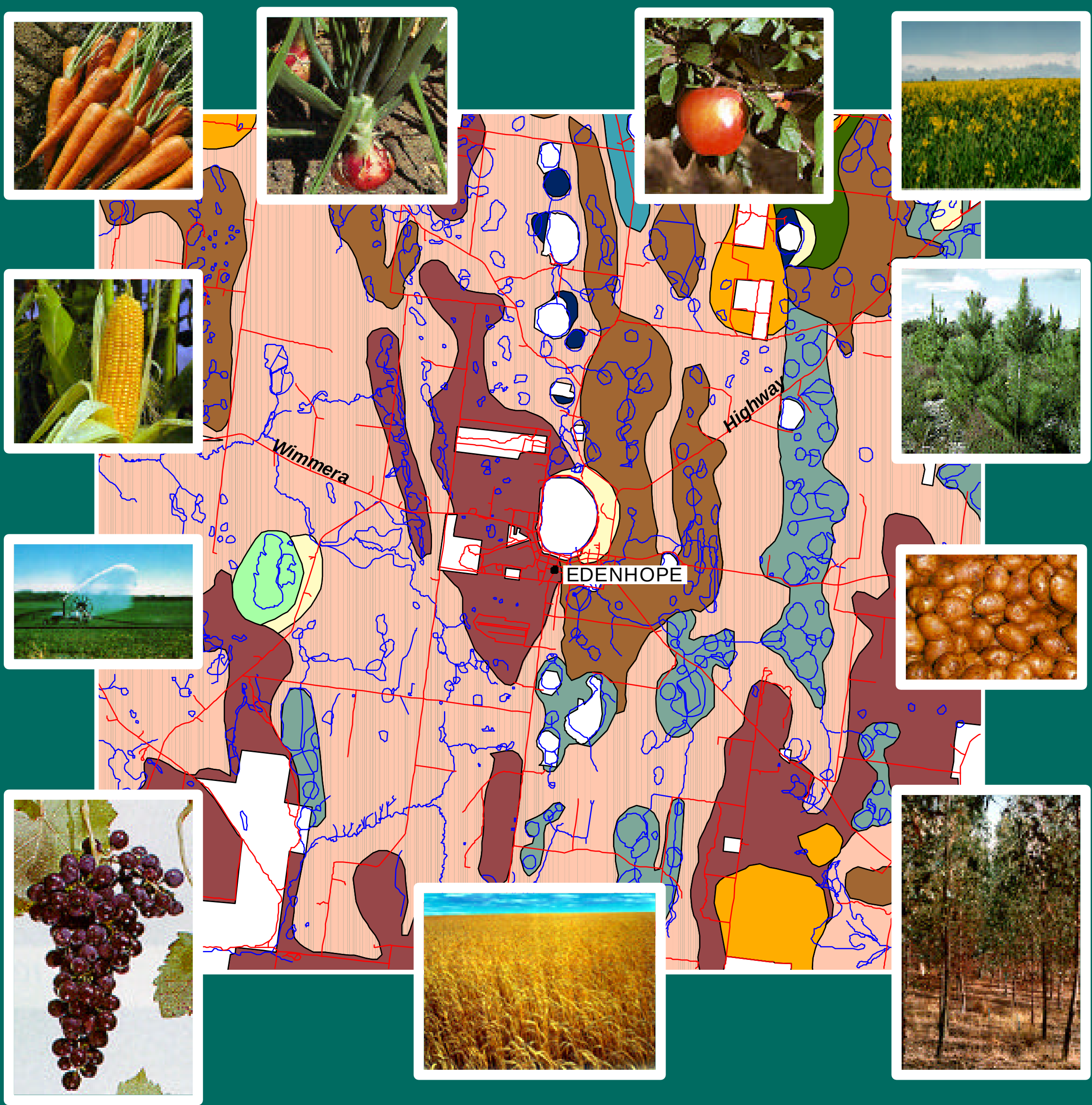

AGRICULTURE VICTORIA
Natural Resources and Environment
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WEST WIMMERA SHIRE COUNCIL

AGRICULTURAL AND HORTICULTURAL LAND SUITABILITY FOR THE WEST WIMMERA SHIRE

Volume 1&2

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Disclaimer
The information presented in this publication is offered by the State of Victoria (Department of Natural Resources and Environment) solely to provide information at the 1:100 000 scale. It is therefore suitable for broad planning purposes rather than at the paddock level. Prior to investment in any new agricultural inductry, the authors strongly advise that further detailed analysis be carried out by an organisation with proven, relevant skills, at the paddock level to further identify limitations and provide detailed management options.

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CONTENTS

Chapter 1
OVERVIEWS AND OUTCOMES

1.1 Introduction

The West Wimmera Shire is a major regional shire located along the Victorian/South Australian border (see Figure 1.1). The shire is predominantly rural based with broadacre cropping, mixed farming and grazing as the major agricultural industries. More recently, other industries such as clover seed production and potatoes have developed, using groundwater as an irrigation source.

The West Wimmera Shire has the potential to increase sustainable agricultural production through the improved utilisation of the natural resource base. With major processing facilities located regionally, increased and diversified agricultural industries have the potential to provide a major regional development stimulus. The shire has a significant groundwater resource that, with careful management, could support a larger irrigated agricultural industry than currently exists.

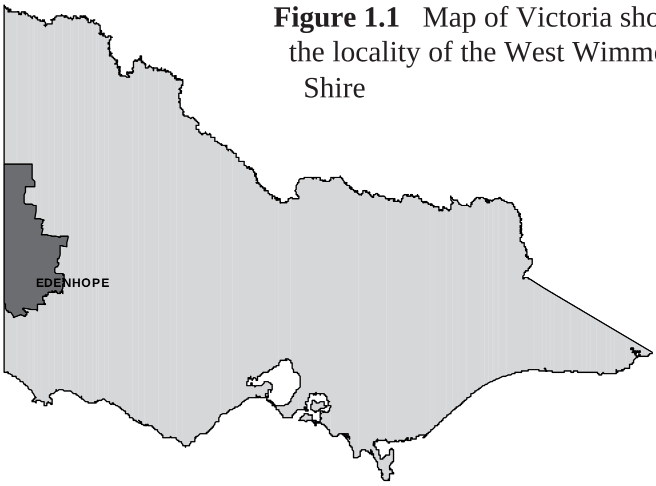

Figure 1.1 Map of Victoria showing the locality of the West Wimmera Shire

The shire has a range of landscapes, soils and climate that show a wide range of suitabilities for dryland agriculture and a greater range of suitabilities for irrigated agriculture. Sustainable future development of agricultural industries requires that each crop or pasture is suited to the particular climate, landscape and soil so that optimal production can be achieved with minimal damage to the environment.

To facilitate the further development of agriculture in the region, the West Wimmera Shire in conjunction with Business Victoria commissioned the Department of Natural Resources and Environment to identify suitable areas for new agricultural enterprises.

This report of Agricultural and Horticultural Land Suitability for the West Wimmera Shire brings together broad information on the land, soil, climate and groundwater resources, and links this with known information on the preferred growth requirements of a range of crops and pastures to identify areas that are suitable for growth. The suitability assessment for a crop/pasture is based on best management practices. The suitability classification (1-3) is based on major limitations that will decrease productive potential or result in detrimental environmental effects both on-site and off-site.

The growth requirements for fourteen crop and pasture species have been assessed and include;
wheat
canola
chickpeas
lentils
clover seed
lucerne seed
potatoes
carrots

onions
sweet corn
grapes
apples
radiata pine
blue gum

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1.2 How to Use this Report

This report is a companion to a Geographical Information System (GIS) computer software located within the West Wimmera Shire. The report can be used as a stand alone document.

The report is divided into a number of sections:
- Background and general information (Chapters 1 and 2)
- General information regarding the preferred climatic, land, soil and irrigation water conditions for the crop and pastures in question (Chapter 3)
- Detailed information on the groundwater in the shire (Chapter 4)
- Detailed information on the land units, key landscape and soil features, and the suitability for each crop and pasture (Chapter 5 and 6)
- Maps presenting the land units within the Shire (rear of the report)

From the land unit maps, locate the area in question and identify the land unit. In Chapter 6, go to the section covering the relevant land unit. This section provides information of the land and soil types within the unit and the suitability and limiting factors for each crop and pasture. The suitabilities are divided into climate, landscape and soil, and are an overall suitability provided for the land unit To interpret this information more generally, refer to Chapter 3. Groundwater suitability is presented as a GIS overlay.

1.3 Geographic Information System User Notes

A number of data layers can be presented by the GIS. A summary of the layers follows.

Base Information

Three layers present the base information for the shire:
- primary roads,
- towns and
- main watercourses.

Climate

Average maximum monthly temperature and average minimum monthly temperature (^{o}C) isohyets are presented for the months of January, March, May, July, September and November.

Average monthly rainfall (mm) isohyets are presented for the months of January, March, May, July, September and November.

Average annual rainfall (mm) isohyets.

Digital climate information was provided by permission of the Bureau of Meteorology.

Land
Land units as described in the report.

Groundwater
Victorian /South Australian Border Zone Agreement zones.

Water level (potentiometric surface, depth of groundwater below the surface (m)) for the Parilla Sands, Murray Group and Renmark Group aquifers.

Salinity/yield matrix (presenting water quality and quantity) for the Parilla Sands, Murray Group and Renmark Group aquifers. Table 1.1 provides a legend for the codes presented.

Table 1.1 Salinity/Yield Matrix interpretation.

Salinity, TDS (mg/L)	**Bore Yield (ML/day)**			
	<0.043	**0.043 - 0.43**	**0.43 - 4.3**	**>4.3**
<500	1,1	1,2	1,3	1,4
500 - 1,000	2,1	2,2	2,3	2,4
1,000 - 1,500	3,1	3,2	3,3	3,4
1,500 - 3,000	4,1	4,2	4,3	4,4
3,000 - 7,000	5,1	5,2	5,3	5,4
7,000 - 14,000	6,1	6,2	6,3	6,4
14,000 - 35,000	7,1	7,2	7,3	7,4
35,000 - 100,000	8,1	8,2	8,3	8,4
>100,000	9,1	9,2	9,3	9,4

Digital groundwater data was provided by permission of the Australian Geological Survey Organisation.

Crop and Pasture Suitabilities
The suitability classes (Table 1.2) for each crop and pasture presented in the layers are based on the representative soil type. The representative soil type has been chosen as the most appropriate to depict the land unit(s). In some units, associated soil types have different suitability classes to the representative soil type and these are presented as class 4 and class 5 (Table 1.2)

Treecover
Treecover across the shire as defined by woody vegetation greater than two mters in height and with a crown cover (foliar density) greater than ten per cent. Treecover is mapped to a minimum of one hectare.

Salinity Discharge and Potential Recharge
This layer is based on information interpreted from the Statewide Land Systems (Rowan, 1990). Broad predictions, classed into high and moderate potential recharge, have been made for the land systems within the shire based on criteria established for state coverage. This layer shows the susceptibility of land to direct recharge (recharge to groundwater from infiltration of rainfall). It does not show the susceptibility to indirect recharge, which is that caused by infiltration from streams, lakes, flooding or ponding.

Salinity discharge areas have been plotted from the best available information compiled over the last two decades. Due to this timeframe, areas shown may not be fully representative of current discharge at these sites. The discharge mapping may not be complete within some shires and new unmapped areas may be present.

Table 1.2 Crop/Pasture suitability definitions

Class	Description	Definition
1	Suitable	Suited - with no major limitations to production or the environment given best management practice. Types of limitations and management options that fall into this category include stubble retention and minimum tillage for wind and water erosion control, liming to ameliorate topsoil acidity and gypsum to ameliorate sodic topsoils.
2	Generally suitable	Suited - but with some major limitations that increases the risk of production loss or environmental damage, even given best management practice. Types of limitations and management options that fall into this category include rainfall that is higher or lower than the pre-ferred level, surface or sub-surface drainage, deep ripping with gyp-sum to improve internal drainage, claying to improve soil wettability.
3	Not suitable	Unsuited - due to major production or environmental limitations that significantly increase the risk of production loss or environmental damage, even given best management practice. These limitations are generally too expensive to overcome with current technology or incapable of being modified.
4		Generally suitable (class 2) although some associated soil types within the land unit are unsuitable (class 3).
5		Unsuitable (class 3) although some associated soil types within the land unit are generally suitable (class 2).

Chapter 2
BACKGROUND INFORMATION

2.1 Landform and geology

The majority of the shire (excluding the southern areas) has a distinctive NNW-SSE topographic pattern, formed by ‘stranded beach ridges’. Many ridges are not prominent in terms of elevation due to past erosion and recent deposition. These ridges are believed to have been formed by the south west retreat of the sea (Murray Gulf) approximately 2-4 million years ago.

The core of the ridges consists of sandstone, and is referred to as *Parilla Sand* on geological maps. Since their formation, some of the ridges have been covered by deposits of windblown (aeolian) sand and calcareous clay. A laterite (ironstone accumulation) layer occurs below the surface horizon on most of the larger ridges, indicating that humid climatic periods have occurred between dry phases during soil development.

In some cases, for instance the Diapur Ridge, the stranded beach ridges are very prominent. Areas in the north of the shire also show evidence of the stranded beach ridges, although the relief is lower than that of the Diapur Ridge. There are also some undulating plains where the stranded beach ridges are evident, although there has been recent depositions of superficial windblown material.

The plains that run between the ridges slope to the north-west. They have been covered by aeolian calcareous clays that overlay sandstone at depth, usually deeper than three metres.

The modern semi-arid climatic conditions are believed to have begun about 400 000 years ago. In this period, aeolian deposition of calcareous clays and siliceous (quartz dominant) sand took place. Of these siliceous deposits, the Lowan sands (white sand) form extensive tongue-shaped dunefields; the major features being the Big and Little Deserts.

Networks of lakes and swamps are common on the low lying areas between the ridges, particularly in the south of the shire. There are often drainage channels or depressions leading to lakes and swamps, consisting predominantly of grey clay soils. Since European settlement there have been some man-made drains constructed that have changed the drainage and flooding regime of some low lying areas.

Many lakes and some swamps have lunettes formed on the eastern side, although their size and soil type are variable depending on the characteristics of the lake bed from which they were formed.

The landscape in the south of the shire forms the edge of the Dundas Tablelands. The landscape is dissected by the Glenelg River with its tributaries incising the Wimmera Plains. The landscape consists of older granite and sedimentary rock surrounded by Tertiary sediments. The soils are often shallow, although due to the high susceptibility of landslip, the lower slopes often have accumulations of colluvial material.

2.2 Geomorphology

The shire falls into three major geomorphic divisions, the majority of which is in the Murray Basin Plain in the north, the Dundas Plateau to the south east and the Otway Basin Plain in the south. Dividing the Murray Basin Plain and the Otway Basin Plain is the Kanawinka Fault. The Murray and Otway Coastal Plains both overlay the older Dundas Plateau. The depositional environments of the sedimentary sequence has determined many landforms that can be observed today. For a detailed review of the geology in the area refer to Brown (1989) and/or Ludbrook (1971).

Murray Basin Plain
Features of the Murray Basin from the Tertiary and Quaternary age (67 million years to present day) have resulted in the relatively low undulating landscape present today. Significant deposition of soil materials has occurred over this period. The depositional processes were dominated by wind blown (aeolian) material, with some areas influenced by swamp (lacustrine), water driven (fluvial) and marine sequences.

The majority of the surface geology has been influenced by aeolian and marine processes with some evidence of surfical geomorphic features. Remnant strandline ridges ten to 30 metres higher than the Tertiary marine Parilla Sand form the most prominent relief in the basin. Overlying the Parilla Sand, the east/west trending surfical Lowan Sand was derived by the aeolian reworking of the Parilla Sand to form sand dunes and plains. Distributed irregularly between the dunes, the fluvio-lacustrine clays of the Shepparton Formation can be up to 20 metres thick (Stradter and Stewart, 1990). Lunette deposits have been formed on the down wind side of perennial and intermittent lakes.

Dundas Plateau
The Ordovician and Silurian periods (505 - 410 million years ago) saw the formation of the Dundas Plateau. The Granodiorite Dundas Plateau is topographically higher than the surrounding geomorphic divisions. This is due to the plateau being extremely resistant to weathering processes. Lateritic deposits overlying the Granodiorite form an undulating topography with the granodiorite observable in well weathered landscapes. For further information on the Dundas Plateau refer to Bradley, et al. (1995).

Otway Basin Plain
The surface topography of the Otway Basin is a low relief plain. This basin has stranded beach dunes consisting of the Lowan Sand equivalent. Only a very small part of the study area falls into the Otway Basin Plain. For further information refer to Stradter and Stewart (1990).

Surface Hydrology
The varying sea levels of the Tertiary age have influenced the surface hydrology of the study area. Most of the hydrological features can be found in the southern region of the West Wimmera Shire, which is mostly attributed to the higher in rainfall in this area. The Glenelg River drains the south and south east areas if the shire, while the Mosquito Creek drains the south west area to the Millicent Coast.

The majority of terminal waterways in the area trend north-west/south-east, and provides the area with many swamps, sink holes and permanent and intermittent lakes. Water in these depressions either infiltrates the underlying aquifer and/or is removed by evaporation (Stradter and Stewart, 1990), depending on the recharge characteristics of the soil. Together poor drainage, low recharge and high evaporation rates leads to salt accumulation in topographically low areas. This process is not the same as groundwater discharge. In areas where karst features are prominent, ground surface subsidence is a land management issue. Hocking (1995) studied stream salinities and concluded that the majority of saline surface water originated from groundwater discharge from the Parilla Sand Aquifer south of Edenhope.

Hydrogeology
Two basins underlie the West Wimmera Shire, the Murray Basin to the north and west, and the Otway Basin to the south east. Three main aquifers occur within these basins. The Pliocene Sands

Aquifer (Parilla Sands of the Murray Basin) overlies the mid to late Tertiary Limestone Aquifer (Murray Group Limestone Aquifer of the Murray Basin and Heytesbury Group Limestone of the Otway Basin), which in turn overlies the lower Tertiary Sand Aquifer (Renmark Group of the Murray Basin and Wangerrip Group of the Otway Basin). Of these aquifers, the Parilla Sands, Murray Group and the Renmark Group are the most important with respect to water exploitation for irrigation.

Virtually all groundwater is ultimately derived, directly or indirectly, from rainfall. Groundwater flow direction of these aquifers depends on the basin - NNW flow for the Murray Basin aquifers and SW flow for Otway Basins aquifers.

A layer of impermeable clay acts as an aquitard between the Parilla Sands Aquifer and the Murray Group Aquifer. The distribution and thickness of the clay varies throughout the shire (Bradley, et al., 1995), with some potential for downward leakage from the Parilla Sands Aquifer to the Murray Group Aquifer. The Parilla Sands Aquifer is generally only saturated in the western limits of the shire and the water level gradually decreases at the eastern side of the shire. At the Otway-Murray Basin divide, the Parilla Sands Aquifer is also saturated, this area has the shallowest depth to watertable in the West Wimmera Shire.

Land within 20 km of the Victorian/South Australian Border is covered by the Victorian - South Australian Border Agreement. This border agreement zone has been established to avoid deleterious effects occasioned by present and future large-scale groundwater withdrawals on the State border of South Australia and Victoria (Stradter and Stewart, 1990). Considerable hydrogeological investigations have been undertaken in this zone (see Stradter and Stewart, 1990; Bradley et al., 1995; Sibenaler and Stradter, 1989; and Dudding, 1990). Some specific hydrogeological assumptions of this section rely on information deduced from the border zone agreement.

2.3 Climate

Rainfall

Throughout the shire, rainfall is biased towards the winter/spring period. Although there is little difference between the rainfall from east to west, there is a slight bias in rainfall towards the east. There is a marked decline in annual rainfall from north to south. Average annual rainfall for a number of locations within the shire is presented in Table 2.1.

Table 2.1 Average annual rainfall for areas in the West Wimmera Shire

Location	**Average annual rainfall (mm)**
Dergholm*	712
Harrow*	600
Edenhope**	576
Goroke**	525
Kaniva**	462
Serviceton*	497
Telopea Downs**	364

* Source; Rainfall Statistics Australia, Australian Government Publishing Service, 1977

** Source, National Climate Centre, Bureau of Meteorology, 1997

The monthly distribution of rainfall for Harrow, Goroke, Kaniva and Telopea Downs is presented in Figure 2.1.

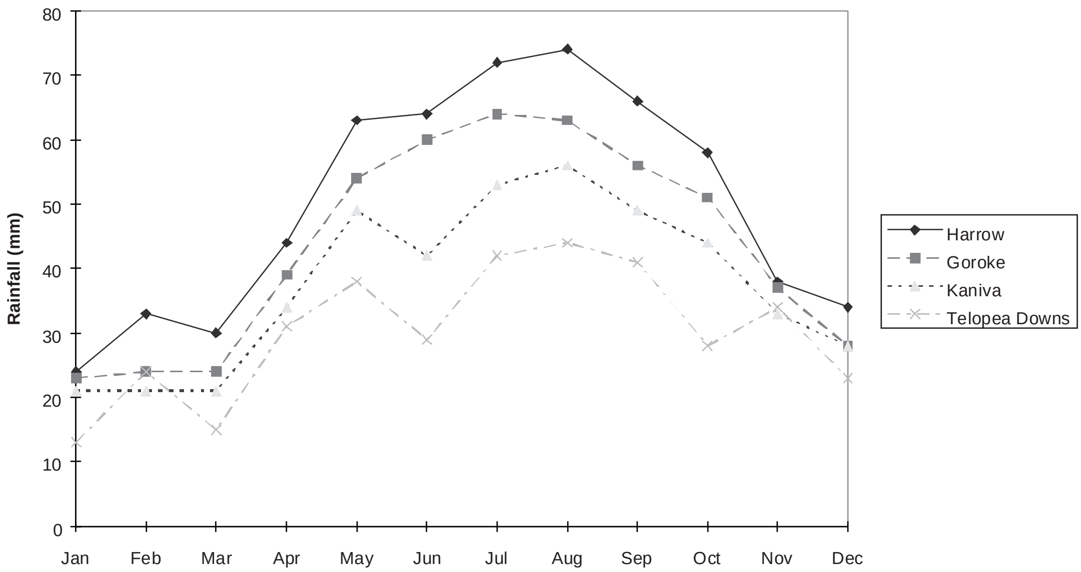


Figure 2.1 Monthly distribution of rainfall for Harrow, Goroke, Kaniva and Telopea Downs

Temperature

The climate of the West Wimmera Shire is characterised by cool winters and warm to hot summers. Average maximum January temperature (AMJaT) is 30°C for all of the shire apart from south of Chetwynd and Powers Creek where the AMJaT temperature is 28°C. Average minimum January temperature is 12°C south of the Little Desert and 14°C north of the Little Desert.

Average maximum July temperature (AMJuT) is 12°C throughout the shire apart from north of Telopea Downs where the AMJuT is 14°C. Average minimum July temperature is 4°C for all of the shire apart from the area to the west of a line between Neuarpurr and Chetwynd where the average minimum July temperature is 6°C.

Frost

All areas in the West Wimmera Shire are prone to frost conditions, although the susceptibility to frost varies widely across the shire. The conditions that instigate frost are complex and are related to many bio-physical aspects including altitude, soil type, position in the landscape and location.

The absence of cloud cover at night allows radiant heat to be transmitted to space therefore resulting in cooler night time temperatures. Cloud cover reduces the amount of heat being radiated back to space thus allowing night time temperatures to remain warmer. Higher areas in the landscape allow cool air to drain to lower areas and are influenced by warm air rising from areas lower in the landscape. Moist soil status assists in the transfer of heat to deeper areas within the soil profile thus increasing the overall temperature of the soil. Dry soils do not transmit heat well, cooling rapidly at night. Soils of low density, such as sands and self mulching (friable) soils, also do not transmit heat well because of the high air filled porosity (air is a poor transmitter of heat). Soils with a high density allow faster heat transmission. Dark coloured soils absorb more heat during the day as compared to lighter colored soils, potentially remaining warmer at night.

In the West Wimmera Shire, the following aspects are critical in increasing the risk of frost:
- dry soil conditions
- deep light coloured sandy soils
- self mulching grey clays
- areas lower in the landscape, i.e. between ridges
- clear skies at night

In contrast, the following aspects are critical in decreasing the risk of frost:
- moist soil conditions
- soils of higher density
- areas higher in the landscape
- cloud cover at night
- proximity to large water bodies

Very little information has been collected across the shire with respect to frost occurrence and severity. The Bureau of Meteorology does not collect frost information within the shire.

Evaporation

Data on evaporation is not collected officially at any location within the West Wimmera Shire. Information taken from Mt. Gambier (Lat 37^{o}44'50S, Long 140^{o}47'10E), Longerenong (Lat 36^{o}40'07S, Long 142^{o}18'05E) and Ouyen (Lat 35^{o}04'15S, Long142^{o}18'52E) (Table 3), which are located to the south west, east and north east of the shire respectively, can provide a general idea of evaporation levels.

Total annual evaporation exceeds rainfall by approximately 2 to 1 in the south and 4 to 1 in the north. Evaporation levels of greater than 100 mm per month occur across the shire from October to March, with greater than 200 mm per month in December for the northern areas and January. Evaporation is lowest in June and July and would approximate rainfall during that period.

Table 2.2 Average total monthly pan evaporation (mm) for Mt. Gambier, Longerenong and Ouyen.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Tot
Mt.G	214	193	151	91	54	35	41	58	79	115	145	188	1367
Long	247	213	170	99	53	34	37	54	81	129	172	225	1528
Ouy	226	187	146	83	50	32	39	61	86	125	171	217	1422

2.4 Soil Fertility

Figures 2.2, 2.3, 2.4 and 2.5 provide general views of surface soil chemical trends across the shire. They are derived from analysis of soil samples submitted from farmers paddocks and research plots to the State Chemistry Laboratory, from 1990 to 1994. In addition, results from analysis of surface soils from this survey have been included in the dataset. Mean values for each analyte have been mapped to each of the land systems identified in this land suitability study. Blank spaces in the maps indicate that insufficient data was available to calculate means for these areas. It should be kept in mind that considerable variation in each analyte will occur within each land system and the mean values mapped only provide an overview of trends for the shire as a whole.

Soil pH

Surface soil pH means range from moderately acid in the southern part of the shire to moderately alkaline on the self-mulching grey clays to the south-west of Kaniva. In general, the lighter textured soils have lower (more acidic) pH values than the heavier textured soils. Specific sites could have more alkaline or more acid surface soil pH than is indicated by this map of mean data. The land suitability study has identified that many soils have strongly alkaline subsoils, which could affect the growth of deep rooted species in particular.

The necessity to apply lime to improve soil pH is mainly confined to the southern part of the shire and more particularly where legumes (e.g. clover, lucerne, pulses) are sown. Problems of trace element deficiency (e.g. zinc) due to high soil pH is largely confined to the heavier soils, although trace elements (e.g. copper, zinc) may also be required on very light textured soils, regardless of soil pH.

Soil Salinity

Soil salinity is estimated by measuring the electrical conductivity (EC) of a soil, water suspension. Surface soil analysis means show only low and harmless levels of salt across the shire, although it is known that a small amount of surface salting has occurred on the edges of the Dundas Tableland in the southern part of the shire.

The land suitability study has identified many soils containing appreciable amounts of soluble salts in the subsoil horizons, which could prove to be of concern for the growth of deep rooted plant species (e.g. lucerne, trees). The potential for irrigation in the shire is also inhibited on some soils due to subsurface salinity. With increased irrigation, there is the risk that soluble salts will gradually rise to the surface and thereby reduce productivity and sustainability.

Soil Available Potassium

Plant available potassium (Skene method) tends to be high on the heavier cropping soils north of the Little Desert but rather low in the sandy soils of Telopea and in the southern part of the shire.

Responses to potassium fertiliser (e.g. Muriate of Potash) would only be expected on the deep sands of the north or in the Little Desert. On duplex soils with shallow and light textured surface horizons over clay subsoils, potassium responses are not observed, despite low surface potassium, as the clays of the subsoils generally have sufficient potassium for plant roots to tap.

Soil Available Phosphorus

Plant available phosphorus (Olsen method) means across the shire are generally low in southern areas and moderate in the cropping soils north of the Little Desert. The range in Olsen phosphorus within each land system would be expected to be very large, depending on cropping history and fertiliser use, and therefore this map should not be used too literally.

Phosphorus responses are still expected on most soils and paddocks throughout the shire; the level of phosphorus fertiliser (e.g. Superphosphate) input depending on target yields, soil phosphorus content, phase of a crop rotation and reliability of rainfall.

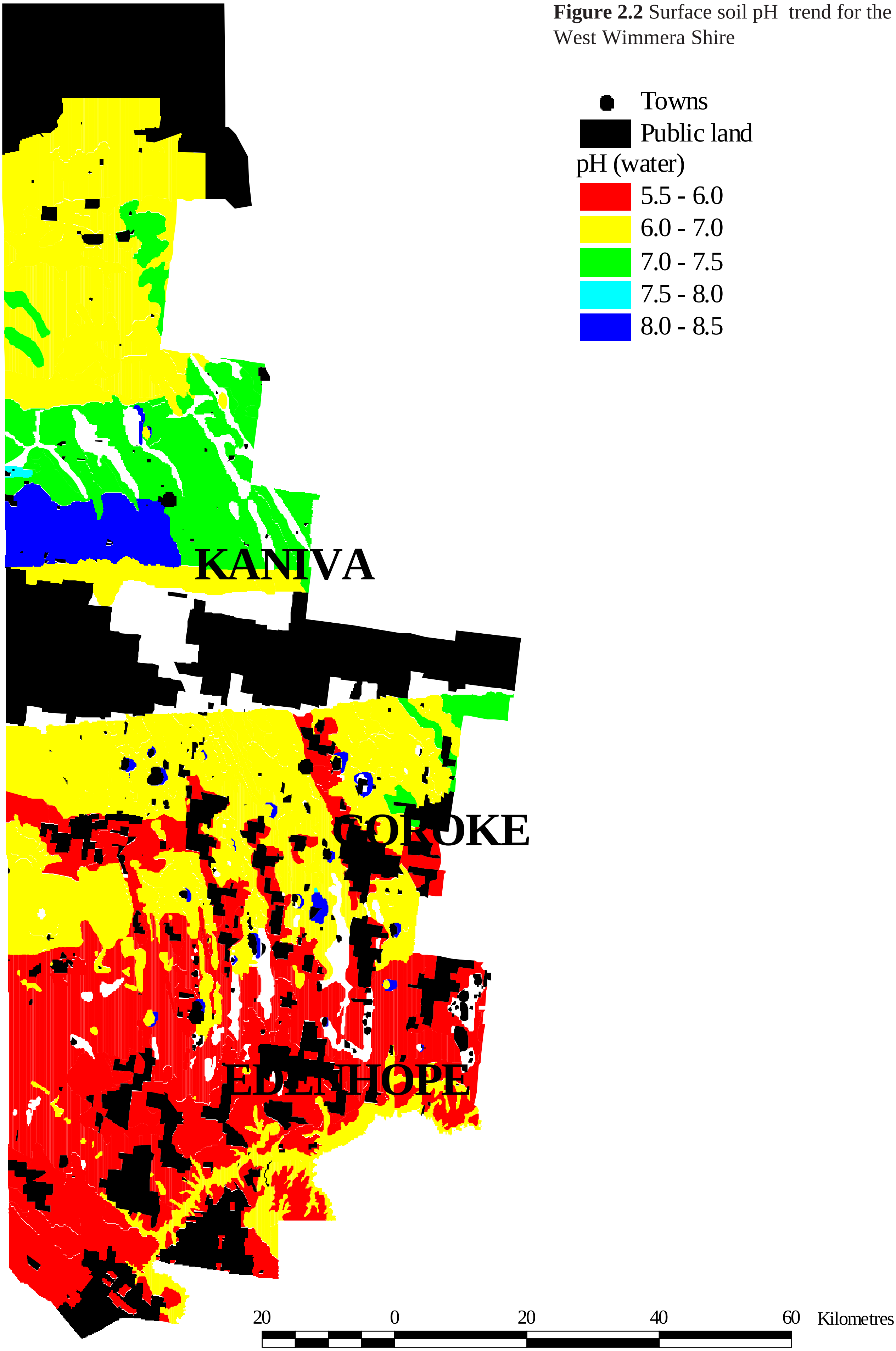


Figure 2.2 Surface soil pH trend for the West Wimmera Shire

Figure 2.3 Surface soil Electrical Conductivity (EC) trend for the West Wimmera Shire

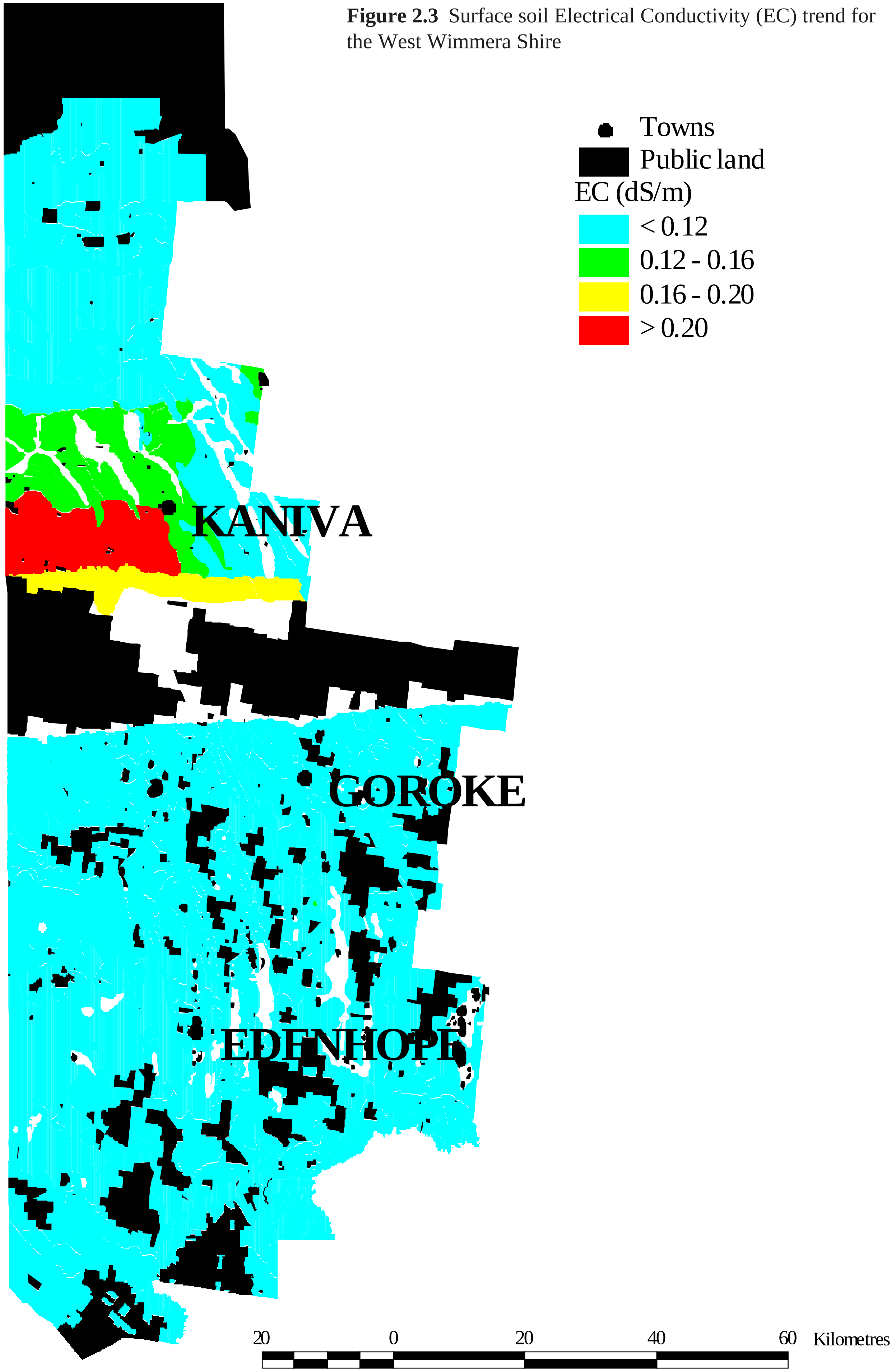


Figure 2.4 Surface soil Potassium (K) trend for the West Wimmera Shire

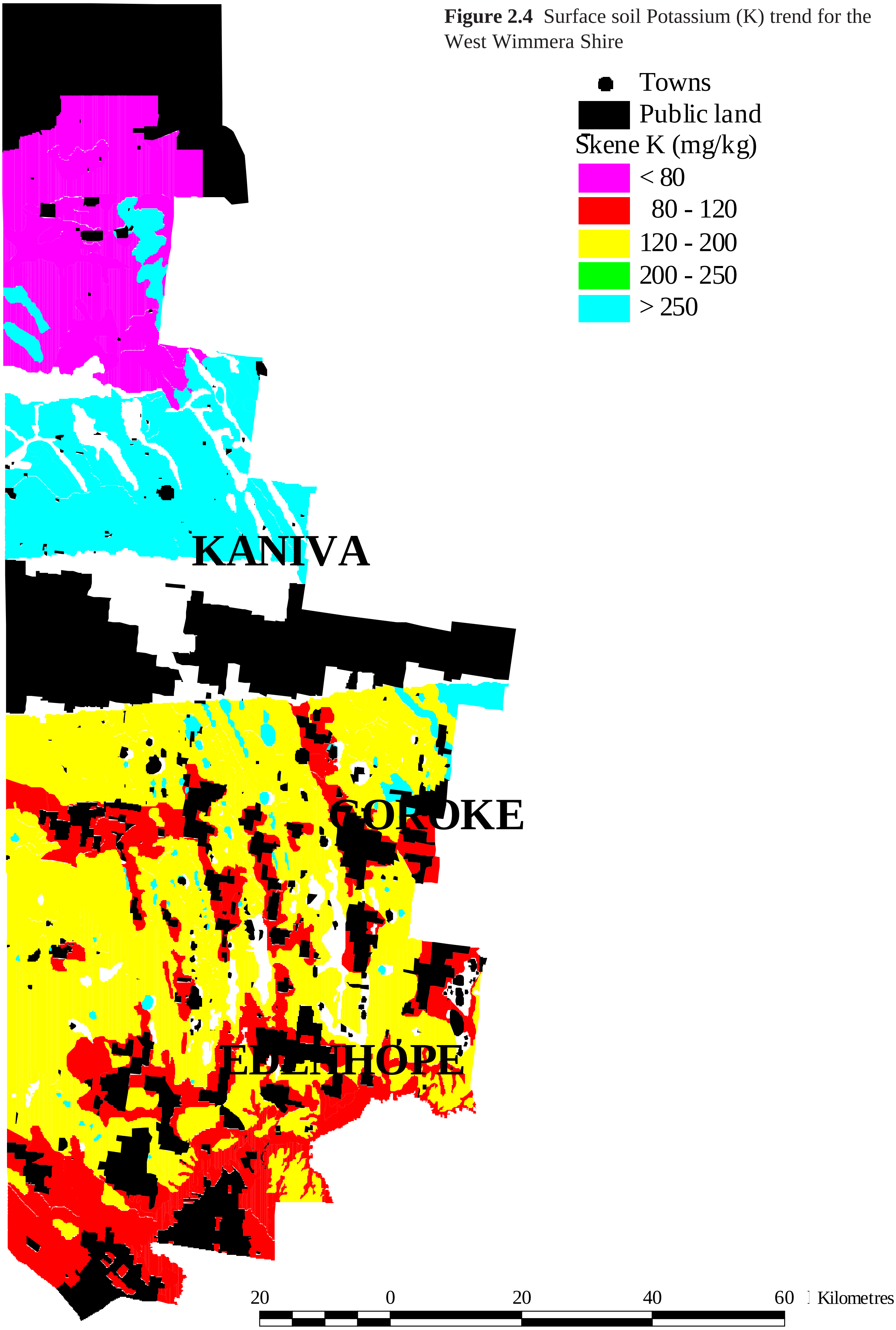
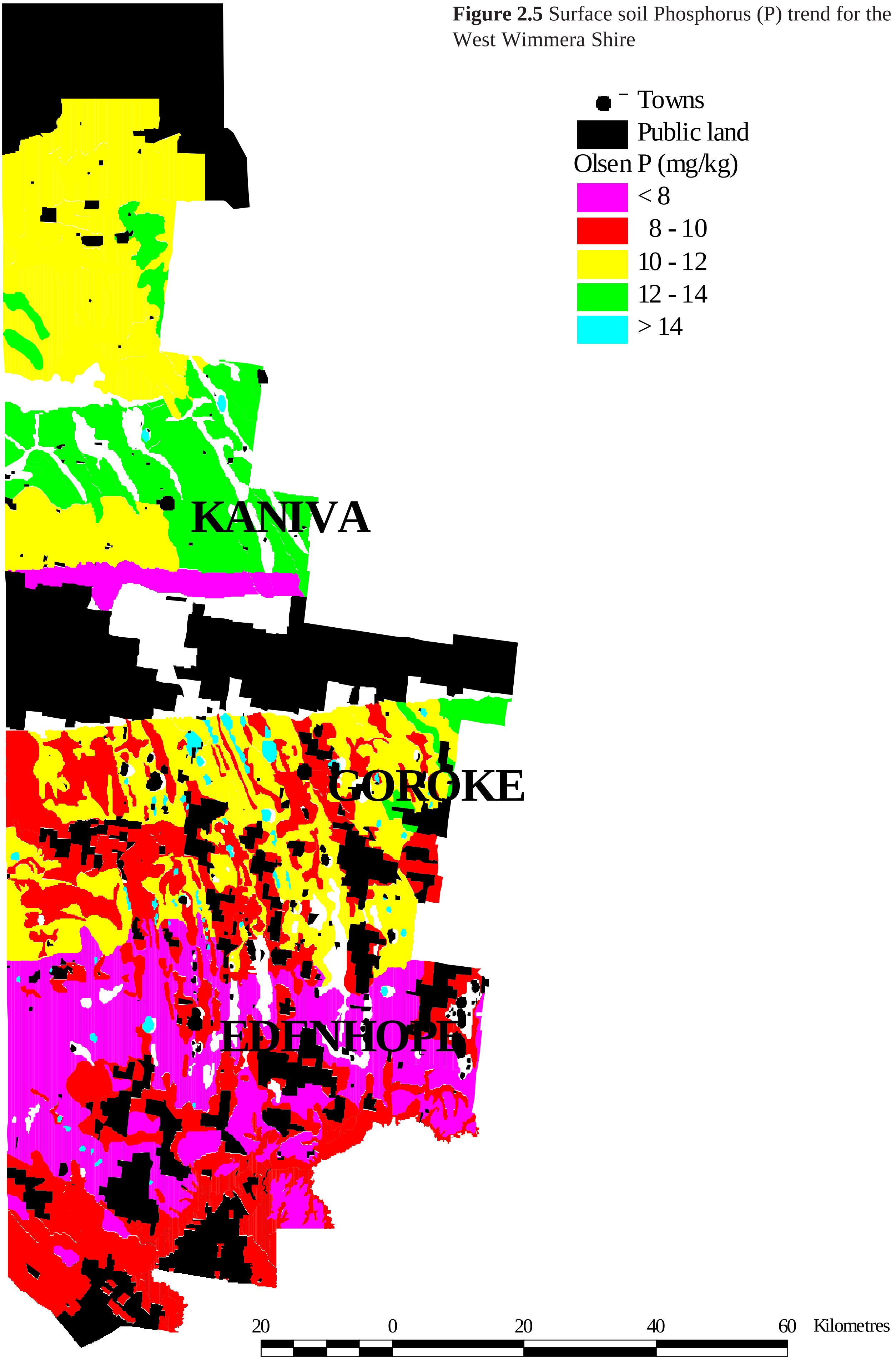


Figure 2.5 Surface soil Phosphorus (P) trend for the West Wimmera Shire



Chapter 3
LAND SUITABILITY

3.1 Land Suitability Rationale and Methodology

The suitability for growing selected crops and pastures in the West Wimmera Shire has been determined based on four components:

- Climate — Is the crop/pasture in question suited to the rainfall, temperature and frost susceptibility within the land unit?
- Landscape — Will growing the crop/pasture result in unacceptable water, wind or gully erosion on the land unit? Will the natural landscape features of the land unit impede machinery operations?
- Soil — Are the inherent soil conditions suitable for growing the crop/pasture?
- Groundwater — Is there a groundwater resource of sufficient quality and quantity to irrigate the crop/pasture?

Each of the above components has sub-components and critical values (e.g. topsoil texture and pH are sub-components for soil) that are used to rate the suitability for the various crops/pastures (Table 3.1). Definitions of the sub-component measurements are presented in Appendix 1.

Table 3.1. Components and sub-components used to determine crop/pasture suitability

Component	Sub-component	Description
Climate	Rainfall	Annual rainfall (mm) or Growing Season Rainfall (April - October) (mm)
Climate	Temperature	Mean monthly temperature (^oC) (selected months), Mean maximum monthly temperature (^oC) (selected months), Chilling hours (below 7^oC; April - August)
Climate	Frost	Frost risk based on relative temperature differentials across the shire
Landscape	Water erosion hazard	Inherent susceptibility of the land to degradation irrespective of management
Landscape	Wind erosion hazard	Inherent susceptibility of the land to degradation irrespective of management
Landscape	Gully erosion hazard	Inherent susceptibility of the land to degradation irrespective of management
Landscape	Rock outcrop	Areal extent of rock outcropping the soil surface (%)
Landscape	Floaters	Extent of soil volume taken up with rock (% volume)
Soil	Topsoil texture	Generalised texture based on texture groupings

Soil	Subsoil texture (top of the B_2 horizon)	Generalised texture based on texture groupings
Soil	Topsoil depth, PPF D	Topsoil depth (cm) for duplex Primary Profile Forms
Soil	Topsoil depth, PPF U	Topsoil depth (cm) for uniform Primary Profile Forms
Soil	Depth to hard rock	Depth of soil to hard rock layers (cm) that are impermeable to roots
Soil	Organic carbon	Organic carbon of the topsoil (%)
Soil	CEC	Highest Cation Exchange Capacity (meq/100g) occurring in the expected rooting depth of the plant
Soil	Topsoil pH	Highest or lowest pH (water) of the topsoil
Soil	Subsoil pH	Highest or lowest pH (water) occurring in the expected rooting depth of the plant
Soil	Soil salinity	Highest soil salinity (ECe, dS/m) occurring in the expected rooting depth of the plant
Soil	Internal drainage	Waterlogging potential of the soil
Soil	Hydrophobicity	Wettability of the soil from a dry state
Groundwater	Quality	Quality of water, total dissolved salts (mg/L)
Groundwater	Quantity	Quantity of water for one crop or pasture (ML/ha)

Sub-components are rated for their limitation to the growth of the crop/pasture or potential for environmental degradation according to a three class rating system (Table 3.2).

In applying suitability ratings to the selected crop and pasture species, critical levels for the sub-components were used to differentiate between the classes. The rationale for the critical values has been twofold: a)based on plant production, and b) based on protecting the natural resource base, with the aim of identifying economically and environmentally sustainable land use and management options. The critical values are based on the best available information and aims to provide an objective method for classification. Because of the complex interactions between soil, landscape and climate components, purely objective assessments can sometimes be misleading and for this reason, critical values are used as a general guide rather than hard and fast rules. To this extent, a level of subjectivity has been used by the authors to provide logical classifications. Justification of the sub-components used and the critical values for the suitability classes for each crop/pasture will follow.

A number of sub-components are used to determine the component suitability. As not all of the sub-components are equal with respect to the limiting ability, the sub-components have been divided into primary and secondary sub-components. Primary sub-components are the major limiting factors while secondary limitations are less limiting. For example, within the soil component, depth of topsoil is more important than topsoil organic carbon for growing potatoes, therefore depth of topsoil is a primary sub-component while organic carbon is a secondary sub-component. In addition, as the crops/pastures in this study have different limiting factors, primary and secondary sub-components will vary depending upon the crop/pasture.

The suitability for a component is determined by the most limiting primary sub-component, and the overall suitability is determined by the most limiting component - climate, landscape or soil.

Groundwater factors are also used as a discriminator for crops/pastures that require irrigation. The suitability for irrigated crops (based on climate, landscape and soil) is also identified for areas that do not have a suitable groundwater resource. In these areas, surface water harvesting may be a possibility. This report does not identify areas suitable for surface water harvesting.

It is important to note that the information provided in this report is based on broad (1:100 000 scale) assessment of the nature of the land, and soils information has been collected from a limited number of point samples. This means that the sub-components, particularly soil information, can only provide a general guide to the condition of the land within a land unit.

Table 3.2. Crop/Pasture suitability definitions

Class	Description	Definition
1	Suitable	Suited - with no major limitations to production or the environment given best management practice. Types of limitations and management options that fall into this category include stubble retention and minimum tillage for wind and water erosion control, liming to ameliorate topsoil acidity and gypsum to ameliorate sodic topsoils.
2	Generally suitable	Suited - but with some major limitations that increases the risk of production loss or environmental damage given best management practice. Types of limitations and management options that fall into this category include rainfall that is higher or lower than the preferred level, surface or sub-surface drainage, deep ripping with gypsum to improve internal drainage, claying to improve soil wettability.
3	Not suitable	Unsuited - due to major production or environmental limitations that significantly increase the risk of production loss or environmental damage given best management practice. These limitations are generally too expensive to overcome with current technology or incapable of being modified.

3.2 Broadacre Non-Irrigated Crops

3.21 Wheat

Suitability critical values for wheat are presented in Table 3.3

Table 3.3. Critical values for determining the suitability for wheat. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall GSR (mm) (Apr - Oct)	200-400	100-200 400-450	<100 >500
Frost risk	LOW	MEDIUM, HIGH	
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<10	10-30	>30
➔Floaters (%)	<10	10-40	>40
Soil			
Topsoil texture	L, CL, LC, S, SL, MHC		-
➔Subsoil texture	L, CL, LC, MHC	SL	S
➔Topsoil depth (cm) PPF D	>20	10-20	<10
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>100	60 - 100	<60
Organic Carbon (%)	>1.0	<1.0	
CEC	>15	<15	
➔pH (topsoil or <30 cm)	5.0-8.5	4.5-5.0 >8.5	<4.5
➔pH (subsoil or >30 cm)	5.5-8.5	4.5-5.5 >8.5	<4.5
➔Soil salinity, ECe (dS/m)	<5.5	5.5-9.0	>9.5
➔Internal drainage	WELL, MODERATELY WELL	IMPERFECTLY	POORLY
➔Hydrophobicity	NO	YES	

➔ Primary sub-component

Climate

Rainfall

Wheat can tolerate a range of climates as indicated by the widespread sowings across Victoria. The main limitations are related to insufficient rainfall, particularly on deep sands, and too much rainfall, which can result in waterlogging on imperfectly drained soils and causing difficulties with the crop maturing and harvesting. The shire has a large number of imperfectly drained soils that, under high rainfall conditions, result in a greater risk of crop loss or failure.

Growing Season Rainfall (GSR) (rainfall from April to October) is used as a guide for suitable climatic areas. GSR has been calculated from annual rainfall. In the West Wimmera Shire, GSR is approximately 75 per cent of annual rainfall.

GSR greater than 400 mm is seen as being less suitable for wheat growing due to the risk of potential water logging problems and maturing and harvesting difficulties in some years. In this situation, drainage of the land may be required. GSR greater than 450 mm is classified as being generally unsuited to wheat cropping.

Frost

Depending on the stage of the season, the susceptibility of wheat to frost damage varies from low to high. Frosts at flowering can severely limit yield, while frosts at other stages during the growing season can reduce the efficacy of herbicides and normal plant growth.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for wheat growing, although high risk areas are identified as being susceptible to yield losses in some years.

Landscape

Landform

Plains and rises are well suited to broadacre cropping with respect to machinery access and operation. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for the removal of vegetative cover from the soil during summer and autumn means that land with a low water erosion hazard is well suited to wheat. Best management practices, such as stubble retention and direct drilling, will allow land with a medium water erosion hazard to be cropped to wheat. Land that has a high water erosion hazard can be generally suitable for wheat with contour drainage, direct drilling and stubble retention.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. The requirement for cultivation during autumn and the potential for removing vegetative cover from the soil during summer and autumn means that soils with a low wind erosion hazard are suitable for wheat. Suitable management, particularly stubble retention and direct drilling, allows land with medium to high wind erosion hazard to be cropped to wheat. Care should be exercised during below average rainfall years on soils with high wind erosion hazard to prevent stock accessing stubbles over the critical summer to autumn period. Maintain a protective soil surface cover by not grazing stubble over the summer and autumn period on soils with high wind erosion hazard.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope is a major factor that increases susceptibility. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. Soils with a high gully erosion hazard are not suited to wheat due to the cyclic nature of annual crops (no perennial roots to stabilise subsoils) and the requirement for cultivation.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, and beyond 30 per cent becomes uneconomic for broadacre agriculture. Rock outcrops also logistically impede machine access and operation.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and damage cultivation equipment. Soil with floaters that occupy more than 40 per cent of the effective plant rooting volume is considered uneconomic for broadacre agriculture.

Soil

Soil Texture, Depth and Hard Rock Layers

Wheat shows superior growth on soils that allow for rapid and deep root exploration (greater than 80 cm). Soils that have moderate to high waterholding capacities, such as loams, clay loams and light clays are well suited to wheat. Sand and sandy loam topsoils and/or subsoils do not have high water or nutrient holding capacities but are still considered suitable for wheat growing although generally less productive. Increased management is required for sand and sandy loam topsoils with respect to preventing wind erosion. Some medium heavy clays topsoils are prone to soil structure problems but are able to be managed with gypsum (if the clays are dispersive), and conservation cropping practices. Sandy loam and sandy subsoils are considered generally suitable and not suitable respectively due to decreased water and nutrient holding capacities.

On duplex (D) soils, deep topsoils (>20 cm) are required for good root proliferation. Topsoils that are less than 10 cm deep and overlay poorly structured subsoils (sodic) increase the risk of crop failure in extreme years. In dry years, poor root penetration reduces drought resistance, and in wet years poor water permeability into the subsoil results in waterlogging. Uniform (U) profiles allow easier root access into the subsoil and therefore topsoil depth is less critical as compared to duplex soils.
The depth to hard rock dictates the depth of soil that can be exploited by plant roots. Shallow soils can severely restrict productivity in drier than average years. At 60 cm

below the surface, hard rock can significantly increase the risk of crop failure through insufficient moisture availability in dry years and potential waterlogging in wet years.

Organic Carbon, Cation Exchange Capacity andExchangeable Cations

Organic carbon provides a broad indicator of topsoil fertility in addition to the susceptibility to soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention, removal of fallows and minimum tillage or direct drilling. Generally, organic carbon levels greater than 1.0 per cent will have reasonable fertility, show fewer topsoil structure problems (assuming the topsoils are not dispersive), and allow for a greater number of crops in a rotation if appropriate conservation tillage practices are adopted. Organic carbon levels less than 1.0 per cent means conservation tillage practices should be adopted, and the number of crops in a rotation should be reduced to enable a longer pasture phase to build up organic carbon levels.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. CEC levels of greater than 15 have the potential for sustained fertility, although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for wheat of 80 cm. The preferred soil pH (suitable, class 1) is between 5.0 and 8.5 for the topsoil and 5.5 and 8.5 in the subsoil. Topsoil pH levels below 5.5 may require lime to ameliorate acidity, or a more acid tolerant variety selected. Ameliorating subsoil acidity is costly and not overly practical. Soil pH levels less than 4.5 can be ameliorated through the addition of lime however this is assumed to be uneconomic for wheat production, particularly if the low pH also occurs at depth. Soils with a pH less than 4.5 are rated as unsuitable (class 3).

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for wheat of 800 mm. Wheat is reasonably tolerant of soil salinity with suitable ECe levels up to 5.5 dS/m. Soil salinity levels above an ECe of 9.5 dS/m are considered not suitable for wheat.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential of the soil. Wheat prefers well drained and moderately well drained conditions (suitable, class 1) but is tolerant of waterlogged conditions over short periods. Imperfectly drained sites are likely to be subject to production losses in wetter than average years (generally suitable, class 2). Surface drainage may decrease the risk of crop damage. However, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable even with surface drainage.

Topsoil Hydrophobicity

Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for wheat as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for wheat growing although management techniques such as stubble retention and reduced tillage are required to minimise soil erosion. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option. It should be noted that soils in this survey have been rated according to their level of hydrophobicity. Soils with severe hydrophobicity may require extensive or repeated claying before improvements in water infiltration are achieved.

3.22 Canola

Suitability critical values for canola are presented in Table 3.4.

Climate

Rainfall

Canola is tolerant of wet conditions, although extended waterlogging during winter and spring will significantly reduce yields, and delay maturation and harvesting. Canola can be grown in areas with up to 700 mm annual rainfall. Above 600 mm annual rainfall, the risk of waterlogging increases. On heavier soils, the risk of soil structure damage from winter and early spring spraying operations also increases in areas with above 600 mm annual rainfall. Surface drainage and strategic spraying operations can reduce this risk. Above 700 mm annual rainfall, the risk of substantial waterlogging is high making these areas generally unsuitable for canola. Below 400 mm annual rainfall, the risk of crop failure is high (van Rees and Ridge, 1994). Areas with lower than 400 mm annual rainfall are classed as unsuitable even though canola for dry areas is currently being bred and some farmers are successfully growing canola on soils with high levels of stored soil moisture.

Frost

Frost during flowering will result in the abortion of flowers, however canola has a long flowering period that can compensate for frost events. Low frost areas are suitable for canola, with medium to high frost risk areas being generally suitable, although in particularly frosty seasons, there is likely to be a yield penalty.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for canola growing, although high risk areas are identified as being susceptible to yield losses in some years.

Table 3.4. Critical values for determining the suitability for canola. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Annual rainfall (mm)	450-600	400-450 600-700	<400 >700
Frost risk	LOW	MEDIUM-HIGH	
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<10	10-30	>30
➔Floaters (%)	<10	10-40	>40
Soil			
Topsoil texture	S, SL, L, CL, LC	MHC	
➔Subsoil texture	L, CL, LC, MHC	SL, MHC	S
➔Topsoil depth (cm) PPF D	>20	10-20	<10
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>100	80 - 100	<80
Organic C (%) (topsoil or <30 cm)	>1.0	<1.0	
CEC	>20	<20	
➔pH (topsoil or <30 cm)	5.0-8.0	4.5-5.0 >8.0	<4.5
➔pH (subsoil or >30 cm)	6.0-8.0	5.5-6.0 >8.0	<5.5
➔Soil salinity, ECe (dS/m)	<2.5	2.5 - 4.0	>4.0
➔Internal drainage	WELL, MODERATELY WELL	IMPERFECTLY	POORLY
➔Hydrophobicity	NO	YES	

➔ Primary sub-component

Landscape

Landform

Plains and rises are well suited to broadacre cropping with respect to machinery access and operation. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for the removal of vegetative cover from the soil during summer and autumn means that land with a low water erosion hazard is well suited to canola. Best management practices, such as stubble retention and direct drilling, will allow land with a medium water erosion hazard to be cropped to canola. Land that has a high water erosion hazard can be generally suitable for canola with contour drainage, direct drilling and stubble retention.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. The requirement for cultivation during autumn and the potential for removing vegetative cover from the soil during summer and autumn means that soils with a low wind erosion hazard are suitable for canola. Suitable management, particularly stubble retention and direct drilling, allows land with medium to high wind erosion hazard to be cropped to canola. Care should be exercised during below average rainfall years on soils with high wind erosion hazard to prevent stock accessing stubbles over the critical summer to autumn period. Maintain a protective soil surface cover by not grazing stubble over the summer and autumn period on soils with high wind erosion hazard.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope is a major factor that increases the susceptibility. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. Soils with a high gully erosion hazard are not suited to canola due to the cyclic nature of annual crops (no perennial roots to stabilise subsoils) and the requirement for cultivation.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, and beyond 30 per cent becomes uneconomic for broadacre agriculture. Rock outcrops also logistically impede machine access and operation.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and damage cultivation equipment. Soil with floaters that occupy more than 40 per cent of the effective plant rooting volume is considered uneconomic for broadacre agriculture.

Soil

Soil Texture, Depth and Hard Rock Layers

Canola is tolerant of a wide range of soil textures, but grows best on soils that are well drained and allow for unimpeded growth of the taproot. Soils that have moderate to high waterholding capacities, such as loams, clay loams and light clays are suitable. Sand and sandy loam topsoils and/or subsoils do not have high water or nutrient holding capacities are suitable but generally less productive. Increased management is required for sand and sandy loam topsoils with respect to preventing wind erosion. Because of canola's requirement for well drained soils, the heavier textured soils are less suited than the medium textured soils. Some medium heavy clay topsoils are prone to soil structure problems but are able to be managed through gypsum (if the clays are dispersive), and conservation cropping practices. Sandy loam and sandy subsoils are considered generally suitable and not suitable respectively due to decreased water and nutrient holding capacities.

On duplex (D) soils, deep topsoils (>20 cm) are required for good root proliferation. Topsoils that are less than 10 cm deep and overlay poorly structured subsoils increase the risk of crop failure in extreme years. In dry years, poor root penetration reduces drought resistance, and in wet years poor water permeability into the subsoil results in waterlogging. Uniform (U) profiles allow easier root access into the subsoil and therefore topsoil depth is less critical as compared to duplex soils.

The depth to hard rock dictates the depth of soil that can be exploited by plant roots. Shallow soils can severely restrict productivity in drier than average years. At 60 cm below the surface, hard rock can significantly increase the risk of crop failure through insufficient moisture availability in dry years and potential waterlogging in wet years.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations

Topsoil organic carbon provides a broad indicator of topsoil fertility in addition to the likely susceptibility to soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention and minimum tillage or direct drilling. Canola requires adequate nutrition, particularly nitrogen and sulphur. Generally, organic carbon levels of greater than 1.0 per cent will have reasonable fertility, show fewer topsoil soil structure problems (assuming the topsoils are not dispersive), and allow for a greater number of crops in a rotation if appropriate conservation tillage practices are adopted. With organic carbon levels less than 1.0 per cent means conservation tillage practices should be adopted, and the number of crops in a rotation should be reduced to enable an increased pasture phase to build up organic carbon levels.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. CEC levels of greater than 20 have the potential for sustained fertility for canola, although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for canola of 80 cm. The preferred soil pH (suitable, class 1) is between 5.0 and 8.0 for the topsoil and 6.0 and 8.0 for the subsoil. Topsoil pH levels less than 6.0 may require lime to ameliorate acidity. Amelioration of subsoil acidity is more costly and not overly practical. Soil pH levels of less than 4.5 can be ameliorated through the addition of lime however this is assumed to be uneconomic, particularly if the low pH occurs at depth. Soils with a pH less than 4.5 are rated as unsuitable (class 3).

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for wheat of 800 mm. Canola is reasonably intolerant of soil salinity with suitable ECe levels of up to 2.5 dS/m. Soil salinity levels above an ECe of 4.0 dS/m are considered not suitable.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential of the soil. Canola prefers well drained and moderately well drained conditions (suitable, class 1) but is tolerant of waterlogged conditions over short periods. Imperfectly drained sites are likely to be subject to production losses in wetter than average years (generally suitable, class 2). Surface drainage may decrease the risk of crop damage. However, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable even with surface drainage.

Topsoil Hydrophobicity

Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for canola as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for canola growing although management techniques such as stubble retention and reduced tillage are required to minimise soil erosion. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option. It should be noted that soils in this survey have been rated according to their level of hydrophobicity. Soils with severe hydrophobicity may require extensive or repeated claying before improvements in water infiltration are achieved.

3.23 Chickpeas

Suitability critical values for chickpeas are presented in Table 3.5.

Table 3.5. Critical values for determining the suitability for chickpeas. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall (mm)	400-500	350-400 500-575	<350 >575
Frost risk	LOW	MEDIUM, HIGH	
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW	MEDIUM, HIGH	

➔Gully erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<10	10-30	>30
➔Floaters (%)	<10	10-40	>40
Soil			
➔Topsoil texture	L, CL, LC	SL, MHC	S
➔Subsoil texture	L, CL, LC	MHC	S, SL
➔Topsoil depth (cm) PPF D	>20	10-20	<10
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>80	<60 - 80	<60
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
CEC	>20	5 - 20	<5
➔pH (topsoil or <30 cm)	5.5-8.5	5.0 - 5.5 >8.0	<5.0
➔pH (subsoil or 30 - 50 cm)	6.0-8.5	5.5 - 6.0 >8.5	<5.5
➔Soil salinity, ECe (dS/m)	<1.5	1.5 - 3.5	>3.5
➔Internal drainage	WELL	MODERATELY WELL	IMPERFECTLY, POORLY
➔Hydrophobicity	NO	YES	

➔ Primary limitation

Climate

Rainfall

Chickpeas require adequate moisture for full yield potential but show a very low tolerance to waterlogging. The preferred annual rainfall range (suitable) is between 425 and 475 mm, but will grow in areas of between 350 and 575 mm annual rainfall. Varietal differences will allow chickpeas to be grown in areas where annual rainfall is as low as 350 mm (Desi) (van Rees and Ridge, 1994), however the risk of crop losses or failure in drier years increases. Below 350 mm is considered unsuitable. Above 575 mm, the risk of waterlogging for long periods (greater than two days) is high and results in crop loss. Areas with above 575 mm annual rainfall are considered unsuitable for chickpeas.

Frost

Chickpeas are susceptible to frost damage during flowering and seed set and will, in some years, result in significant crop damage. All areas of the shire are prone to frost, the risk of damage dependent upon when the frost occurs. Low frost areas are preferred for chickpeas, whereas medium and high frost areas are likely to result in yield losses if frosts occur during August to September period.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for chickpea growing, although high risk areas are identified as being susceptible to yield losses in some years.

Landscape

Landform

Plains and rises are well suited to broadacre cropping with respect to machinery access and operation. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for the removal of vegetative cover from the soil during summer and autumn means that land with a low water erosion hazard is well suited to chickpeas. Best management practices such as stubble retention and direct drilling will allow land with a medium water erosion hazard to be cropped to chickpeas. Land that has a high water erosion hazard can be generally suitable for chickpeas with contour drainage, direct drilling and stubble retention.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. The requirement for cultivation during autumn and the potential for removing vegetative cover from the soil during summer and autumn means that soils with a low wind erosion hazard are suitable for chickpeas. Suitable management, particularly stubble retention and direct drilling allows land with medium to high wind erosion hazard to be cropped to chickpeas. As chickpeas do not produce high stubble covers, maximising the retention of stubbles from earlier crops and maintaining the chickpea stubble in a standing condition is an important management option for soils with medium to high wind erosion hazard. Care should be exercised during below average rainfall years on soils with high wind erosion hazard to prevent stock accessing stubbles over the critical summer and autumn period. Maintain a protective soil surface cover by not grazing stubble over the summer autumn period on soils with medium and high wind erosion hazard.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope is a major factor that increases susceptibility. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. Soils with a high gully erosion hazard are not suited to chickpeas due to the cyclic nature of annual crops (no perennial roots to stabilise subsoils) and the requirement for cultivation.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation and beyond 30 percent becomes uneconomic for broadacre agriculture. Rock outcrops also logistically impede machine access and operation.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damage cultivation equipment. Soil with floaters that occupy more than 40 per cent of the effective plant rooting volume is considered uneconomic for broadacre agriculture.

Soil

Soil Texture, Depth and Hard Rock Layers

Chickpeas prefer medium textured topsoils particularly loams, clay loams and light clays. Heavy clays and sandy loams are generally suitable, and sands are considered poor (Lamb, 1992). Chickpeas show a very poor tolerance to waterlogging and therefore requiring good drainage. Increased management is required for lighter textured soils, such as sandy loams, with respect to preventing wind erosion. Dispersive clay topsoils will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Sandy loam and sandy subsoils are considered not suitable due to poor water and nutrient holding capacities.

Chickpeas have a taproot and also a number of major secondary roots that should be able to exploit subsoils for optimum productivity. On duplex (D) soils, deep topsoils (>20 cm) are required for good root proliferation. Topsoils that are less than 10 cm deep and overlay poorly structured subsoils increase the risk of crop failure in extreme years. In dry years, poor root penetration reduces drought resistance, and in wet years poor water permeability into the subsoil results in waterlogging. Uniform (U) profiles allow for easier root access into the subsoil and therefore topsoil depth is less critical as compared to duplex soils.

The depth to hard rock dictates the depth of soil that can be exploited by plant roots. Shallow soils can severely restrict productivity in drier than average years. At 60 cm below the surface, hard rock can significantly increase the risk of crop failure through insufficient moisture availability in dry years and potential waterlogging in wet years.

Organic Carbon, Cation Exchange Capacity and Exchageable Cations

Organic carbon provides a broad indicator of topsoil fertility and the susceptibility to soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention and minimum tillage or direct drilling. Chickpeas require adequate nutrition for both growth and rihzobia functioning (nitrogen fixation). Organic carbon levels greater than 1.5 per cent will have reasonable fertility, show fewer topsoil structure problems (assuming the topsoils are not dispersive), and allow for a greater number of crops in a rotation if appropriate conservation tillage practices are adopted. At organic carbon levels less than 1.5 per cent means conservation tillage practices should be adopted, and the number of crops in a rotation should be reduced to enable an increased pasture phase to build up organic carbon levels.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. Chickpeas require more fertile soils for adequate productivity as compared to wheat. CEC levels of greater than 20 have the potential for sustained fertility, although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for chickpeas of 60 cm. The preferred soil pH (suitable, class 1) is between 5.5 and 8.5 for the topsoil and 6.0 and 8.5 for the subsoil. Topsoil pH levels less than 6.0 may require lime to ameliorate acidity. Subsoils with pH levels of less than 5.5 are considered unsuitable due to the difficulty of ameliorating acid subsoils. Topsoil pH levels less than 5.0 can be ameliorated through the addition of lime however this is assumed to be uneconomic. Soils with a pH less than 5.0 are rated as unsuitable (class 3). On highly alkaline soils, boron toxicity may become a problem for chickpeas.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for chickpeas of 60 cm. Chickpeas are intolerant of soil salinity with suitable ECe levels of up to 1.5 dS/m. Soil salinity levels above an ECe of 3.5 dS/m are considered not suitable.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Chickpeas require well drained conditions (suitable, class 1) and can tolerant minor waterlogging (< 2 days). Moderately well drained sites are likely to be subject to production losses in wetter than average years. Surface drainage may decrease the risk of crop damage, however the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Imperfectly and poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable even with surface drainage.

Topsoil Hydrophobicity

Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for chickpeas as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for chickpea growing although management techniques such as stubble retention and reduced tillage are required to minimise soil erosion. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option. It should be noted that soils in this survey have been rated according to their level of hydrophobicity. Soils with severe hydrophobicity may require extensive or repeated claying before improvements in water infiltration are achieved.

3.24 Lentils

Suitability critical values for lentils are presented in Table 3.6.

Climate

Rainfall

Lentils require adequate moisture for full yield potential but show a very low tolerance to waterlogging. The preferred annual rainfall range (suitable) is between 450 and 550 mm, but will grow in areas of between 400 and 600 mm annual rainfall depending upon variety. Kye can be grown in areas down to 400 mm annual rainfall, while later maturing varieties such as Laird are suitable for higher rainfall areas (Lamb, 1993). Wetter areas at risk of waterlogging or on soils that are moderately well drained, surface drainage may be required. Below an annual rainfall of 400 mm is considered unsuitable for lentils due to the risk of significant crop failures in drier years. Above 600 mm, the risk of waterlogging for long periods (greater than two days) is high and results in crop loss. Areas with above 600 mm annual rainfall are considered unsuitable for lentils.

Frost

As lentils are a new crop in Victoria, little information is available regarding the frost susceptibility of lentils, however it is assumed that lentils will show a similar response to chickpeas. Chickpeas are susceptible to frost damage during flowering and seed set which, in some years, will result in significant crop damage. All areas in the shire are prone to frost, the risk of damage dependent upon when the frost occurs. Low frost areas are preferred for chickpeas whereas medium and high frost areas are likely to result in yield losses if frosts occur during the August to September period.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for lentil growing, although high risk areas are identified as being susceptible to yield losses in some years.

Table 3.6. Critical values for determining the suitability for lentils. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall (mm)	450-550	400-450 550-600	<400 >600
Frost risk	LOW	MEDIUM, HIGH	
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<10	10-30	>30
➔Floaters (%)	<10	10-40	>40
Soil			
➔Topsoil texture	L, CL, LC	SL, MHC	S
➔Subsoil texture	L, CL, LC	MHC	S, SL
➔Topsoil depth (cm) PPF D	>20	10-20	<10
➔Topsoil depth (cm)	>5	<5	

PPF U			
Depth to hard rock (cm)	>80	60 - 80	<60
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
CEC	>20	5 - 20	<5
➔pH (topsoil or <30 cm)	5.5-8.5	5.0 - 5.5 >8.0	<5.0
➔pH (subsoil or 30 - 50 cm)	6.0-8.5	5.5 - 6.0 >8.5	<5.5
➔Soil salinity, ECe (dS/m)	<1.5	1.5 - 3.5	>3.5
➔Internal drainage	WELL	MODERATELY WELL	IMPERFECTLY, POORLY
➔Hydrophobicity	NO	YES	

➔ Primary limitation

Landscape

Landform

Plains and rises are well suited to broadacre cropping with respect to machinery access and operation. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for the removal of vegetative cover from the soil during summer and autumn means that land with a low water erosion hazard is well suited to lentils. Best management practices such as stubble retention and direct drilling will allow land with a medium water erosion hazard to be cropped to lentils. Land that has a high water erosion hazard can be generally suitable for lentils with contour drainage, direct drilling and stubble retention.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. The requirement for cultivation during autumn and the potential for removing vegetative cover from the soil during summer and autumn means that soils with a low wind erosion hazard are suitable for lentils. Suitable management, particularly stubble retention and direct drilling allows land with medium to high wind erosion hazard to be cropped to lentils. As lentils do not produce high stubble covers, maximising the retention of stubbles from earlier crops and maintaining the chickpea stubble in a standing condition is an important management option for soils with medium to high wind erosion hazard. Care should be exercised during below average rainfall years on soils with high wind erosion hazard to prevent stock accessing stubbles over the critical summer and autumn period. Maintain a protective soil surface cover by not grazing stubble over the summer autumn period on soils with medium and high wind erosion hazard.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope is a major factor that increases susceptibility. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. Soils with a high gully erosion hazard are not suited to lentils due to the cyclic nature of annual crops (no perennial roots to stabilise subsoils) and the requirement for cultivation.

Rock Outcrop and Floaters
Rocks outcropping the soil surface decrease the area of land suitable for cultivation and beyond 30 percent becomes uneconomic for broadacre agriculture. Rock outcrops also logistically impede machine access and operation.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damages cultivation equipment. Soil with floaters that occupy more than 40 per cent of the effective plant rooting volume is considered uneconomic for broadacre agriculture.

Soil
Soil Texture, Depth and Hard Rock Layers
Lentils prefer medium textured soils, particularly loams, clay loams and light clays. Medium heavy clays and sandy loams are less suitable, and sands are considered poor (Lamb, 1992). Lentils show a very poor tolerance to waterlogging and therefore require good drainage. Increased management is required for lighter textured soils, such as sandy loams, with respect to preventing wind erosion. Dispersive clay topsoils will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Sands and sandy loam subsoils are not suited to lentil growing due to poor nutrient and water holding capacities.

Lentils require adequate rooting depth to optimise productivity. On duplex (D) soils, deep topsoils (>20 cm) are required for good root proliferation. Topsoils that are less than 10 cm deep and overlay poorly structured subsoils increase the risk of crop failure in extreme years. In dry years, poor root penetration reduces drought resistance, and in wet years poor water permeability into the subsoil results in waterlogging. Uniform (U) profiles allow easier root access into the subsoil and therefore topsoil depth is less critical as compared to duplex soils.

The depth to hard rock dictates the depth of soil that can be exploited by plant roots. Shallow soils can severely restrict productivity in drier than average years. At 60 cm below the surface, hard rock can significantly increase the risk of crop failure through insufficient moisture availability in dry years and potential waterlogging in wet years.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations
Organic carbon provides a broad indicator of topsoil fertility and the susceptibility to soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention and minimum tillage or direct drilling. Lentils require adequate nutrition for both growth and rihzobia functioning (nitrogen fixation. Organic carbon levels greater than 1.5 per cent will have reasonable fertility, show fewer topsoil soil structure problems (assuming the topsoils are not dispersive), and allow for a greater number of crops in a rotation if appropriate conservation tillage practices are adopted. At organic carbon levels less

than 1.5 per cent means conservation tillage practices should be adopted, and the number of crops in a rotation should be reduced to enable an increased pasture phase to build up organic carbon levels.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. Lentils require more fertile soils for adequate productivity as compared to wheat. CEC levels of greater than 20 have the potential for sustained fertility, although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for lentils of 60 cm. The preferred soil pH (suitable, class 1) is between 5.5 and 8.5 for the topsoil and 6.0 and 8.5 for the subsoil. Topsoil pH levels less than 6.0 may require lime to ameliorate acidity. Subsoils with pH levels less than 5.5 are considered unsuitable due to the difficulty of ameliorating acid subsoils. Topsoil pH levels less than 5.0 can be ameliorated through the addition of lime however this is assumed to be uneconomic. Soils with a pH less than 5.0 are rated as unsuitable (class 3). On highly alkaline soils, boron toxicity may become a problem for lentils.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for lentils of 60 cm. Lentils are tolerant of soil salinity with suitable ECe levels of up to 1.5 dS/m. Soil salinity levels above an ECe of 3.5 dS/m are considered not suitable.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Lentils require well drained conditions (suitable, class 1) and can tolerant minor waterlogging (< 2 days). Moderately well drained sites are likely to be subject to production losses in wetter than average years. Surface drainage may decrease the risk of crop damage, however the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Imperfectly and poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable even with surface drainage.

Topsoil Hydrophobicity

Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for lentils as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for lentils although management techniques such as stubble retention and reduced tillage are required to minimise soil erosion. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option. It should be noted that soils in this survey have been rated according to their level of hydrophobicity. Soils with severe hydrophobicity may require extensive or repeated claying before improvements in water infiltration are achieved.

3.3 Irrigated Broadacre Pasture Seeds

3.31 White Clover Seed

Suitability critical values for clover seed is presented in Table 3.7.

Climate

Rainfall

White clover for seed production is normally grown in areas that are drier than the normal growing environment for the plant. This is to minimise seed contamination (genetic contamination) problems from other clovers. White clover requires good soil moisture levels to maximise seed production, therefore irrigation is required to allow growth in areas that would normally be too dry. Generally, annual rainfall of greater than 650 mm is required for rain-fed white clover production and is therefore considered unsuitable for white clover seed production.

Table 3.7. Critical values for determining the suitability for white clover seed. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall (mm)	<600	600 - 650	>650
Frost risk	LOW - MEDIUM	HIGH (OCT-NOV)	
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully Erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<5	5-15	>15
➔Floaters (%)	<10	10-20	>20
Soil			
Topsoil texture	L, CL, LC, MHC	SL	S
➔Subsoil texture	CL, LC, MHC	L	S, SL
➔Topsoil depth (cm) PPF D	>20	10-20	<10
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (m)	>0.8	0.6-0.8	<0.6
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	

CEC	>20	<20	
➔pH (topsoil or < 30 cm)	5.0 - 7.5	4.5 - 5.0 7.5-8.5	<4.5 >8.5
➔pH (subsoil or 30 - 50 cm)	5.5 - 7.5	5.0 - 5.5 7.5 - 8.5	<5.0 >8.5
➔Soil salinity, ECe (dS/m) to 50 cm	<1.0	1.0 - 2.5	>2.5
➔Internal drainage	WELL, MODERATELY WELL	IMPERFECTLY	POORLY
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS mg/L)	<500	500 - 850	>850
Quantity (ML/ha)	>4	3 - 4	<3

➔ Primary limitation

Frost

Frost during flowering (October) will reduce seed set and potential yields. The extended flowering period of clover reduces this risk and makes the crop suitable for low to medium frost areas. High frost areas are generally suitable although there may be a yield penalty in some years.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for white clover growing, although high risk areas are identified as being susceptible to yield losses in some years.

Landscape

Landform

Plains and rises are well suited to broadacre cropping and therefore clover seed production with respect to machinery access and operation, particularly irrigation equipment. Low hills are suitable but require considered management for machinery access and operation and for surface water run-off control.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for removing vegetative cover from the soil during summer and autumn means that land with a low water erosion hazard is well suited to clover seed production. Suitable management, such as pasture residue retention and careful grazing management over the summer and autumn period, should allow land with a medium water erosion hazard to be cropped to clover. Land that has a high water erosion hazard is also suitable for clover growing if water control practices such as contour drainage, and pasture residue retention and careful summer/autumn grazing practices are adopted.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. The requirement for cultivation during autumn and the potential for removing vegetative cover from the soil during summer and autumn means that soils with a low wind erosion hazard are suitable for white clover. Suitable management, particularly residue retention, maintaining the growth of the stand over summer/autumn with irrigation and careful grazing, allows land with medium to high wind erosion hazard to be cropped to clover.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope and unused excess water in the soil profile are major factors that increase susceptibility. The shallow rooted nature of clover plants and the requirement for irrigation makes clover seed production unsuited to high gully erosion hazard areas.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, generally make centre pivot irrigation systems unviable and cause harvesting difficulties. Clover requires harvesting close to the soil surface and rock outcrop of greater than 15 per cent surface area impedes machine function and increase the risk of harvesting machine damage. Areas with rocks outcropping more than 15 per cent of the surface are considered unsuitable for clover.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damages cultivation equipment. Soil with floaters that occupy more than 20 per cent of the effective plant rooting volume is considered uneconomic for intensive agriculture.

Soil

Soil Texture, Depth and Hard Rock Layers

White clover will grow on a wide range of topsoil textures providing there is adequate fertility, moderate drainage and water holding capacity. Clay topsoils that are dispersive will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Sandy loam and sand topsoils are considered generally suitable and unsuited respectively due to nutrient and water holding restraints. Sand or sandy loam subsoil textures are not suitable for white clover due to the ease of nutrient leaching (under irrigation) and its affect on plant growth.

Adequate topsoil depth is required for nutrient holding and drainage. On duplex (D) soils, topsoil depths greater than 20 cm are suitable, and less than 10 cm are unsuitable. Uniform (U) profiles allow for water drainage and easier root access into the subsoil, and therefore topsoil depth required is less as compared to duplex soils.

Hard rock layers that are 60 cm or shallower below the surface are considered unsuitable for white clover due to the increased risk of crop failure through potential waterlogging in wet years or following over irrigation.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations

Organic carbon provides a broad indicator of topsoil fertility and the susceptibility to soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as residue retention and minimum tillage or direct drilling. Clover requires adequate nutrition for growth, seed production and rhizobia functioning (nitrogen fixation). Organic carbon levels greater than 1.5 per cent will have reasonable fertility and show fewer topsoil structure problems (assuming that the topsoils are not dispersive). Organic carbon levels less than 1.5 per cent are considered generally suitable for clover seed production but may show poorer fertility on lighter textured soils.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients and ability to withstand soil pH changes. Clover, being a legume, will fix nitrogen, an excess of which can acidify soils. This is a potential problem with successive clover crops. Higher CEC will provide long term protection against pH changes due to acidification. Clover for seed production requires fertile soils for adequate productivity and soils that are moderately well buffered against pH reduction. CEC levels of greater than 20 have the potential for sustained fertility while less than 20 are generally suitable, although a regular and balanced fertiliser programme is still required. Low CEC levels, although generally suitable, are likely to acidify at a faster rate and require more frequent applications of lime to ameliorate acidity.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for clover of 500 mm. The preferred soil pH (suitable, class 1) for clover is between 5.0 and 7.5 for the topsoil and 5.5 and 7.5 for the subsoil. Topsoil pH levels less than 6.0 may require lime and less than 4.5 are considered unsuitable. Subsoil pH levels below 5.0 are considered unsuitable due to the cost and difficulty in ameliorating subsoil acidity. Topsoil and subsoil pH levels greater than 8.5 are considered unsuitable due to potential nutrient imbalances and toxicities.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for clover of 500 mm. White clover is intolerant of high soil salinity levels. ECe levels up to 1.0 dS/m are suitable and soil salinity levels above an ECe of 2.5 dS/m are considered unsuitable.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. White clover prefers well drained and moderately well drained conditions (suitable, class 1), but will tolerant waterlogging conditions of one week or more that may occur on imperfectly drained soils. Waterlogging during the flowering period may result in a yield penalty. Imperfectly drained soils are generally suitable although surface drainage may be required to remove excess water if waterlogging commonly occurs for periods greater than one week. The fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable regardless of surface drainage.

Topsoil Hydrophobicity

Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for white clover as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for white clover growing however management techniques such as claying, stubble retention and reduced tillage are required to minimise soil erosion and maximise the infiltration of applied irrigation water. If waterings occur at intervals that do not allow the surface soil to dry out, the effect of hydrophobicity will be minimised.

Groundwater

Quality

Clover is intolerant of high salt levels in irrigation waters. Irrigation water quality less than 500 mg/L total dissolved salts (TDS) is considered suitable, with generally suitable water quality levels up to 850 mg/L TDS. At higher levels, up to 15 per cent extra water quantity may need to be applied to leach accumulated salts in the soil profile. Water quality levels of greater than 850 mg/L TDS is considered unsuitable for irrigating clover even with increased volumes of additional water.

Quantity

Water quantity for clover irrigation is difficult to generalise with two confounding factors being rainfall and rooting depth. A minimum of 4 ML/ha is required for seed production as well as maintenance of the stand for grazing through the summer/autumn period. Three ML/ha will suffice if the stand is to be irrigated for seed production only.

Other Issues

The number of sunny days is important at flowering time to ensure good seed set. Bees are only active on bright days, and bee activity is one influencing factor on clover seed productivity. In some areas, locating hives in or close to the stand at flowering time may be required to optimise seed set.

3.32 Lucerne for Seed Production

Suitability critical values for lucerne is presented in Table 3.8.

Climate

Rainfall

Lucerne for seed production is suited to areas that are not common lucerne growing areas in order to minimise seed contamination (genetic contamination) from other local stands. Such areas include the more arid zones or wetter areas dominated by cropping. Irrigation is required to optimise yield. Most of the West Wimmera Shire is suited to dryland lucerne production apart from areas in the south where waterlogging and low soil pH are major limiting factors. Therefore rainfall alone is a poor criteria for identifying suitable areas and more detailed local investigation will be required such as the proximity of other lucerne stands.

The preferred rainfall range for dryland lucerne is between 450 and 600 mm, but it will grow in areas with annual rainfall of 300 mm and up to 700 mm. In areas with over 600 mm annual rainfall, waterlogging and low pH levels are likely to become the major limiting factors to growing lucerne. Areas with greater than 700 mm annual rainfall are considered unsuitable for lucerne in the shire as these areas are often associated with poor internal drainage and lower soil pH levels.

Table 3.8. Critical values for determining the suitability for lucerne. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
Frost risk	LOW, MEDIUM	HIGH	
Landscape			
➔Landform	P, R, LH	H, M	
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM, HIGH	
➔Rock outcrop (%)	<5	5-15	>15
➔Floaters (%)	<10	10-20	>20
Soil			
Topsoil texture	S, SL, L, CL, LC, MHC		
➔Subsoil texture	CL, LC, MHC	S, SL, L	
Topsoil depth (cm) PPF D	>10	<10	
Topsoil depth (cm) PPF U	>5	<5	
Depth to hard rock (cm)	>150	100 - 150	<100
Organic C (%) (topsoil or <30 cm)	>1.0	<1.0	
CEC	<20	>20	
➔pH (topsoil or < 30 cm)	5.0 - 8.5	4.5 - 5.0 >8.5	<4.5
➔pH (subsoil or 30 cm to 100 cm)	6.0 - 8.5	5.5 - 6.0 >8.5	<5.5
➔Soil salinity, ECe (dS/m) to 100 cm	<2	2.0 - 3.5	>3.5
➔Internal drainage	WELL	MODERATELY WELL	IMPERFECTLY, POORLY
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS mg/L)	<1500	1500 - 2000	>2000
Quantity			

➔ Primary limitation

Frost
Lucerne is tolerant of frosts for general pasture production. Seed yield is likely to be limited by frosts during flowering. However, the long period over which lucerne flowers will compensate for moderate frosts. Extensive frosts during flowering will cause yield reductions.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for lucerne growing, although high risk areas are identified as being susceptible to yield losses in some years.

Landscape
Landform
Plains, rises and low hills are well suited to lucerne pasture production and grazing. Low hills can limit hay and seed production with respect to machinery access and operation however, with good management are still generally suitable.

Water Erosion Hazard
Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The perennial nature of lucerne and requirements for significantly less cultivation compared to annual cropping makes this enterprise suited to low and medium water erosion soils. However, high water erosion soils are still generally suitable. Considered management is required for medium and high water erosion soils in that overgrazing and exposure of the soil surface will increase the risk of erosion. Controlled grazing is therefore required particularly during the summer/autumn period. Contour drainage may be required on long slopes with high water erosion hazard to control surface water run-off.

Wind Erosion Hazard
Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Maintaining vegetative cover on the soil surface through the summer-autumn period by controlled grazing will allow lucerne to be grown on soils with low, medium and high wind erosion hazards. A minimum of 80 per cent vegetative soil cover is required for protection of medium and high wind erosion hazard soils.

Gully Erosion Hazard
Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope and excess water in the profile are major factors that increase gully erosion susceptibility. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. The deep rooted nature and high water using capacity of lucerne is useful in stabilising gully erosion hazard soils if other soil factors are appropriate (such as subsoil pH), and irrigation scheduling is carefully monitored to minimise excess water in the profile.

Rock Outcrop and Floaters
Rocks outcropping the soil surface decrease the area of land suitable for lucerne, impedes machine access and operation, and creates difficulties with centre pivot

irrigation systems. High levels of rock outcrop (>15 per cent) decrease the viability of irrigated lucerne for hay or seed, but still provides a viable option for dryland lucerne production.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and damage cultivation equipment. Soil with floaters that occupy more than 20 per cent of the effective plant rooting volume is considered detrimental and unsuitable for irrigated lucerne production due to the risk of insufficient water storage capacity in the soil to maintain viable plant numbers through the summer-autumn period.

Soil

Soil Texture, Depth and Hard Rock Layers

Lucerne will tolerate a range of topsoil textures as long as the soil structure allows adequate drainage and aeration. Dispersive clay topsoils will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Subsoil texture is more critical for lucerne with respect to water holding capacity and drainage. Sands, sandy loams and loams are only generally suitable due to poorer water holding capacity. This can be offset if the subsoil is deep allowing a greater volume of soil for root exploitation. Other subsoil textures are suitable if drainage is adequate.

Lucerne is not tolerant of waterlogging. Duplex soils that restrict the movement of water into the subsoil are limiting for lucerne production. Deeper topsoils on duplex (D) soils decrease the risk of plant loss from waterlogging during establishment and topsoil depths of greater than 10 cm is considered suitable. Topsoil depth of less than 10 cm increases the risk of plant mortality in wetter years if drainage is impeded. Amelioration of dispersive clay topsoils and subsoils with gypsum will also decrease the risk of plant mortality. Uniform (U) profiles allow easier root and moisture access into the subsoil and therefore topsoil depth required is less as compared to duplex soils. The treatment of dispersive clay topsoils and subsoils may also decrease the risk of plant mortality through waterlogging on uniform soils.

Hard rock layers can severely restrict productivity in drier than average years. At 100 cm below the surface, impeding layers can significantly increase the risk of lucerne failure through insufficient moisture availability in dry years and potential waterlogging in wet years, or following excessive irrigation. Generally suitable soils for lucerne have no hard rock layers shallower than 1.0 m and suitable soils have no hard rock layers shallower than 1.5 m.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations

Topsoil organic carbon provides a broad indicator of topsoil fertility in addition to the susceptibility to soil structure decline following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention and minimum tillage or direct drilling. Lucerne requires adequate nutrition for both growth and rhizobia functioning (nitrogen fixation). The nutrient requirements are partially off-set by the deep rooted nature of the plant, which increases the volume of soil able to be exploited for nutrients.

For lucerne, organic carbon levels greater than 1.0 per cent will have reasonable fertility and show fewer topsoil soil structure problems (assuming the topsoils are not dispersive). Organic carbon levels of less than 1.0 per cent are still suitable for lucerne, however attention to fertiliser and soil structure is required during the plant establishment phase.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients and ability to withstand soil pH changes. Lucerne for seed production requires more fertile soils for adequate productivity and soils that are moderately well buffered against pH reduction. Lucerne, being a legume, will fix nitrogen. Nitrogen produced to excess can leach and acidify soils. Higher CEC will provide long term protection against pH changes. CEC levels of greater than 20 have the potential for sustained fertility while less than 20 generally suitable, although a regular and balanced fertiliser programme is still required. Low CEC levels can lead to greater acidification rates. Such soils may require more frequent applications of lime to ameliorate acidity.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for lucerne of greater than one metre. Low soil pH levels are not suited for lucerne due to the risk of aluminium toxicity. Not all low pH level soils have high levels of available aluminium, and soil testing of top and subsoils provides a more accurate indication of potential problems rather than relying on soil pH alone.

The preferred topsoil pH (suitable, class 1) is between 5.0 and 8.5 and between 6.0 and 8.5 for the subsoil. Topsoil pH levels of less than 6.5 may require lime to ameliorate acidity when establishing lucerne. Subsoils with pH levels less than 6.0 are considered unsuitable for lucerne (class 3) due to the cost and difficulty of ameliorating subsoil pH. Topsoil pH levels less than 4.5 can be ameliorated through the addition of lime, however this is likely to be uneconomic. Topsoils with a pH of less than 4.5 are considered unsuitable (class 3) for lucerne.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for lucerne of greater than one metre. Lucerne is intolerant of high soil salinity levels. ECe levels of up to 2.0 dS/m are suitable while soil salinity levels above an ECe of 3.5 dS/m are not considered suitable.

Internal Drainage
Internal drainage is used as an indicator of waterlogging potential. Lucerne requires well drained conditions (suitable, class 1) and can tolerate minor waterlogging (< 2 days) that may occur on moderately well drained soils (generally suitable, class 2). Moderately well drained sites are likely to be subject to production losses or plant mortality in wetter than average years. Surface drainage may decrease the risk of crop damage, however the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Imperfectly and poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable regardless of surface drainage.

Topsoil Hydrophobicity
Hydrophobicity (water repellent or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state (e.g. summer and autumn rains). Hydrophobic soils result in decreased available water for crop/pasture use, and increases surface water run-off and the risk of soil erosion. Topsoils that are not hydrophobic are suitable for lucerne as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for lucerne growing however management techniques such as claying, stubble retention and reduced tillage are required to minimise soil erosion and maximise the infiltration of applied irrigation water. If waterings occur at intervals that do not allow the surface soil to dry out, the effect of hydrophobicity will be minimised.

Groundwater
Quality
Irrigation water quality of less than 1,500 mg/L total dissolved salts (TDS) is considered suitable, with water quality levels up to 2,000 mg/L TDS generally suitable. At higher levels, up to 15 per cent extra water quantity may need to be applied to leach accumulated salts in the soil profile. Water quality levels greater than 2,000 mg/L TDS are considered unsuitable for irrigating lucerne even with increased volumes of addition water.

Quantity
Water quantity for lucerne irrigation is difficult to generalise with two confounding factors being rainfall and rooting depth. It is assumed that water quantities of under 4 ML/ha would be unviable for lucerne irrigation.

3.4 Irrigated Horticultural Crops

3.41 Viticulture
Suitability critical values for viticulture is presented in Table 3.9.

Climate
Climate for viticulture is based on grapes being used for wine production.

Mean January Temperature
Adequate temperature throughout the growing season (October to March/April) is critical for vine growth and fruit ripening. The number of degree days is a method

used to estimate climatic suitability for viticulture. Dry and Smart (1988) report that degree days are well correlated with Mean January Temperature (MJT). MJT of 20 - 23°C is suitable for the production of grapes for general wine. Cooler areas with a MJT down to 19°C is seen as desirable for grape production for high quality wine. Although wine grape production occurs in areas with MJT as low as 17°C, below a MJT of 19°C, the risk of insufficient ripening prior to winter increases, and is therefore considered unsuitable.

Table 3.9. Critical values for determining the suitability for viticulture. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Mean January Temperature (°C)	21-23	19-20 24-25	>25 <19
Frost risk	LOW	MEDIUM, HIGH	
Landscape			
➔Landform	P, R, LH	H	M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM, HIGH		
➔Gully erosion hazard	LOW, MEDIUM	HIGH	
➔Rock outcrop (%)	<5	5-20	>20
➔Floaters (%)	<10	10-20	>20
Soil			
Topsoil texture	S, SL, L, CL, LC	MHC	
➔Subsoil texture	L, CL, LC, MHC	SL	S
Topsoil depth (cm) PPF D	>30	<30	
Topsoil depth (cm) PPF U	>5	<5	
Depth to hard rock (cm)	>200	100 - 200	<100
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
CEC	>15	<15	
➔pH (topsoil or <30 cm)	5.0 - 8.0	4.5 - 5.0 >8.0	<4.5
➔pH (subsoil or 30 cm to 100 cm)	6.0 - 8.0	5.0 - 6.0 >8.0	<5.0
➔Soil salinity, ECe (dS/m)	<1.5	1.5-3.0	>3.0
➔Internal drainage	WELL	MODERATELY WELL	IMPERFECTLY, POORLY
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS mg/L)	<800	800-2,000	>2,000
Quantity (ML/ha) [1]if water quality is between 1,000-2,000 mg/L	>4	2-4 3-4[1]	<2[2]

➔ Primary limitation

Frost

Frost at bud-burst and flowering can severely damage the yield potential for the season. Areas with low frost susceptibility are suited to grape production. Areas with medium and high frost susceptibility are generally suitable if varieties that have a later bud-burst, e.g. cabernet sauvignon, and/or using frost protection devices such as windmills are used.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for grape growing, although high risk areas are identified as being susceptible to yield losses in some years.

Other Climatic Factors

Other climatic factors are relevant to viticulture that require consideration prior to vineyard establishment include:

- hail frequency, particularly from flowering onwards
- wind speed, velocity and frequency
- excessive rain from flowering to harvest
- aspect

Landscape

Landform

Plains, rises and low hills are well suited to grape production with respect to machine access and operation. Hills are generally suitable but more considered management is required to control water run-off from within the rows and vehicle tracks. In addition, the layout of the vineyard requires careful planning to ensure safe machine operation.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The perennial nature of grapevines and requirements for significantly less cultivation compared to annual cropping (with appropriate inter-row management), makes this enterprise generally suited for low, medium and high water erosion soils. Medium and high water erosion hazard soils require vegetative cover to be maintained along the inter-rows throughout the year. On high water erosion hazard soils, contour drainage may be required on longer slopes to control surface water flows.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Maintaining vegetative cover on the soil surface through the summer autumn periods by not mechanically fallowing between the rows will allow grapes to be grown on soils with low, medium and high wind erosion hazards with minimal risk. A minimum of 80 per cent vegetative soil cover is required for protection of medium and high wind erosion hazard soils.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion is initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope and excess water in the soil profile are major factors that increase the susceptibility to gully erosion. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. The deep rooted nature of grapes is useful in stabilising gully erosion hazard soils if irrigation is appropriately managed. Promoting good crop or pasture cover between the rows will assist in stabilising the soil.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for grape production and impede machinery access and operation. Rock outcrop areas of greater than 20 per cent are considered unsuitable for grape production.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and damage cultivation equipment. Soil with floaters that occupy more than 20 per cent of the effective plant rooting volume is considered detrimental for effective plant growth and unsuitable for grape production.

Soil

Soil Texture, Depth and Hard Rock Layers

Grapes are suited to a wide range of topsoil textures. Medium to heavy clay topsoils require considered management with respect to soil structure management of the inter-rows. Medium heavy clay topsoils that are dispersive will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Deep sandy soils have poor nutrient and water holding capacities, and sand subsoils are not considered suitable for viticulture. Good fertiliser management will be required on other lighter soils to maintain productivity.

Duplex soils that have dispersive (sodic) clay subsoils impede water movement into the subsoil, which can result in waterlogging of the topsoil. Topsoil depths of greater than 30 cm allow for good root exploration of the soil and allow more water to be stored in the topsoil than shallower topsoils. Dispersive clay subsoils can sometimes be improved by ripping and dropping gypsum down the rip lines prior to vineyard establishment.

Uniform (U) profiles allow easier root and moisture access into the subsoil and therefore topsoil depth required is less compared to duplex soils. The treatment of dispersive clay topsoils and subsoils with gypsum and perhaps deep ripping should also occur prior to vineyard establishment.

Hard rock layers can restrict productivity in drier than average years through a reduction in the volume of soil that can be exploited for water. At 100 cm below the surface, hard rock layers can significantly increase the risk of decreased production through insufficient moisture availability in dry years and potential waterlogging in wet years, or following excessive irrigation. Hard rock layers deeper than 100 cm are considered generally suitable, and deeper than 200 cm are suitable.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations
Organic carbon provides a broad indicator of topsoil fertility in addition to susceptibility of soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as sowing inter-row crops and green manuring. A vegetative cover over the soil surface will be required to protect topsoil structure and minimise wind erosion. Organic carbon levels greater than 1.5 per cent will have reasonable fertility and show fewer topsoil soil structure problems (assuming that the topsoils are not dispersive). Organic carbon levels less than 1.5 per cent are still suitable for grape production but extra attention to fertility and soil structure is required during the plant establishment phase. Minimising tillage and maintaining a good legume based grass cover between the rows will assist in increasing organic carbon levels and soil structure.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. Grapes require more fertile soils for adequate productivity. CEC levels of greater than 15 have the potential for sustained fertility although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH
Limiting soil pH levels are identified at any depth over the assumed rooting depth for grapes of greater than 100 cm. Grapes have a preferred topsoil pH range of between 5.0 and 8.0 and a subsoil pH range of between 6.0 and 8.0 (suitable, class 1). However, grapes will grow successfully in soils with pH levels in excess of 8.0 and below 5.0. Subsoil pH levels less than 5.0 can be overcome with lime however, this is assumed to be uneconomic due to the difficulty of getting significant lime to depth. Topsoils with a pH of less than 4.5 are considered unsuited for grape growing due to the high cost of treatment, particularly where subsoils also need treatment.

Soil Salinity
Soil salinity levels that may limit production are identified at any depth over the assumed rooting depth for grapes of greater than 1.0 m. Grapes are intolerant of high soil salinity. ECe levels up to 1.5 dS/m are considered suitable. Soil salinity levels above an ECe of 3.0 dS/m are considered not suitable. Tolerant root stocks can allow grapes to grow in soils with ECe levels of up to 5 dS/m.

Internal Drainage
Internal drainage is used as an indicator of waterlogging potential. Grapes require well drained conditions (suitable, class 1) but can tolerate minor waterlogging that may occur on moderately well drained soils (generally suitable, class 2). Moderately well drained sites are likely to be subject to production losses in wetter than average years.

Surface drainage can be improved by mounding and/or controlling surface water flows in areas higher in the landscape. Improved drainage may also be provided by the installation of sub-surface drains (e.g. tile drains) prior to planting, however the costs are often high. In considering surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Amelioration of sodic topsoils and subsoils with gypsum may increase internal drainage. Imperfectly and poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem with summer and autumn rains and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for crop/pasture use, and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for grape growing as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for grape growing only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater

Quality

Irrigation water quality of less than 800 mg/L total dissolved salts (TDS) is considered suitable for irrigating grapes. Water quality levels up to 2000 mg/L TDS are considered generally suitable. At higher salt levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. Water quality levels of greater than 2000 mg/L TDS are considered unsuitable for irrigating grapes even with increased volumes of additional water.

Quantity

Water quantity for irrigation is dictated by evaporative demands and rainfall during the growing season. Available water quantities of greater than 4.0 ML/ha over the growing season are considered suitable. Water quantities of 2.0 ML/ha are generally suitable unless the water quality is above 1000 mg/L TDS, in which case at least 3.0 ML/ha should be available. Available water quantity levels of less than 2.0 ML/ha are considered unsuitable.

Other Issues

Herbicide drift

Grapes are highly susceptible to damage from highly volatile herbicides such as 2,4-D esters. In some cases, herbicides can drift up to 10 km, with the potential for complete or partial defoliation of the vineyard if the drift occurs at a critical stage, such as budburst or flowering. Likewise, herbicides used in the vineyard should be applied with care, giving due regard to neighbouring properties and wildlife. The type of agricultural enterprises and management in the local area need to be considered prior to vineyard establishment.

Pest animal damage

Ringbarking of vines by rabbits and hares can cause significant damage to vineyards.

Birds can cause significant damage to the crop close to harvest. Bird repellent devices or netting of the grapes may be required in some areas.

3.42 Apples

Suitability critical values for apple production is presented in Table 3.10.

Climate

Temperature

Apples do best in climates with cold winters and mild to warm summers. Mean maximum January temperature (MMJT) is used as an indicator of summer temperature with areas of MMJT less than 28°C considered suitable, and MMJT up to 30°C generally suitable. Above 30°C MMJT, the risk of hot summer temperatures, excessive days higher than 41°C increases, which can have detrimental impacts on fruit size and quality. Different apple varieties are suited to different climates, e.g. Pink Lady being suited to the hotter areas and Red Delicious to the cooler areas.

Apples have a chilling requirement during their dormant period before growth commences in the spring. The minimum chilling requirement for apples is 700 hours below 7°C. The whole of the West Wimmera Shire has the appropriate number of chilling hours for apples.

Frost

Apples are frost sensitive during flowering and when the fruit is young. Areas with low frost risk are suited to apple production. Areas with medium and high frost risks are generally suitable if management options such as late flowering apple varieties and/or frost protection devices such as over head sprinklers are used.

Frost risk is only used as a guide due to the difficulty in determining the exact frost severity and frequency in areas of the shire. Therefore, frost risk is not used to identify unsuitable areas for apple growing, although high risk areas are identified as being susceptible to yield losses in some years.

Other Climatic Factors

Other climatic factors relevant to apple growing that require consideration prior to orchard establishment include:

- hail frequency, particularly from flowering onwards
- wind speed, velocity and frequency
- excessive rain from flowering to harvest
- aspect
- in hotter areas, sunburn of the fruit may decrease quality in some years.

Table 3.10. Critical values for determining the suitability for apples. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Mean Maximum January Temperature (°C)	<28	28 - 30	>30
Frost risk	LOW	MEDIUM, HIGH	

➔Chilling requirement (hours)	>700		<700
Landscape			
➔Landform	P, R, LH	H	M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM, HIGH		
➔Gully erosion hazard	LOW	MEDIUM, HIGH	
➔Rock outcrop (%)	<5	5-20	>20
➔Floaters (%)	<10	10-20	>20
Soil			
Topsoil texture	SL, L, CL, LC	S, MHC	
➔Subsoil texture	L, CL, LC, MHC	SL	S
➔Topsoil depth (cm) (duplex profile only)	>25	15 - 25	<15
➔Depth to hard rock (cm)	>150	80 - 150	<80
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
CEC	>15	<15	
➔pH (topsoil or < 30 cm)	5.0 - 7.5	4.5 - 5.0 7.5 - 8.0	<4.5 >8.0
➔pH (subsoil or 30 cm to 80 cm)	6.0 - 7.5	5.5 - 6.0 7.5 - 8.0	<5.5 >8.0
➔Soil salinity, ECe (dS/m) (to 80 cm)	<1.5	1.5 - 3.0	>3.0
➔Internal Drainage	WELL	MODERATELY WELL, IMPERFECTLY	POORLY
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS mg/L)	650	650 - 1,000	>1,000
Quantity (ML/ha)	>8	9.5	<8

➔ Primary limitation

Landscape

Landform

Plains, rises and low hills are well suited to apple production with respect to machine access and operation. Hills are generally suitable but more considered management is required to control water run-off from within the rows and vehicle tracks. In addition, the layout of the orchard requires careful planning to ensure safe machine operation.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The perennial nature of orchards and requirements for significantly less cultivation compared to annual cropping (with appropriate inter-row management), makes this enterprise generally suited for low, medium and high water erosion soils. Medium and high water erosion hazard soils require vegetative cover to be maintained along the inter-rows throughout the year. On high water erosion hazard soils, contour drainage may be required on longer slopes to control surface water flows.

Wind Erosion Hazard
Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Maintaining vegetative cover on the soil surface through the summer autumn periods by not mechanically fallowing between the rows will allow apples to be grown on soils with low, medium and high wind erosion hazards with minimal risk. A minimum of 80 per cent vegetative soil cover is required for protection of medium and high wind erosion hazard soils.

Gully Erosion Hazard
Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion is initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope and excess water in the soil profile are major factors that increase the susceptibility to gully erosion. Stabilisation of subsoils with plant roots or gypsum (if practical) decreases the risk of gullying. The deep rooted nature of apples is useful in stabilising gully erosion hazard soils if irrigation is appropriately managed. Promoting good crop or pasture cover between the rows will assist in stabilising the soil.

Rock Outcrop and Floaters
Rocks outcropping the soil surface decrease the area of land suitable for apple production and impede machinery access and operation. Rock outcrop areas of greater than 20 per cent are considered unsuitable for apple production.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and damage cultivation equipment. Soil with floaters that occupy more than 20 per cent of the effective plant rooting volume is considered detrimental for effective plant growth and unsuitable for apple production.

Soil

Soil Texture, Depth and Hard Rock Layers
Apples grow on a range of topsoil textures but prefer the medium textured soils such as sandy loams, loams and clay loams and light clays (suitable, class 1). However, sands and medium clays are generally suitable (class 2) as topsoils. Topsoils in the sand, sandy loam and medium heavy clay classes require considered management with respect to wind erosion protection (sands and sandy loams) and soil structure management (medium to heavy clays). Medium to heavy clay topsoils that are dispersive will require amelioration with gypsum to improve soil structure conditions and therefore drainage and aeration. Sand subsoils are considered unsuitable due to poor nutrient and water holding capacity.

Duplex (D) soils that have dispersive (sodic) clay subsoils impede water movement into the subsoil and can result in waterlogging of the topsoil. Dispersive clay subsoils may be improved by ripping and placing gypsum along the rip line prior to orchard establishment. Duplex soils with a topsoil depth of greater than 25 cm is preferred for apples however, mounding to increase topsoil depth and surface drainage is a viable management option on all but soils with the shallowest topsoils (less than 15 cm).

Topsoil clay dispersibility should also be ameliorated with gypsum prior to orchard establishment. Uniform (U) profiles allow easier root and moisture access into the subsoil and therefore topsoil depth required is less compared to duplex soils. The treatment of dispersive clay topsoils and subsoils with gypsum and perhaps deep ripping should also occur prior to vineyard establishment. Topsoil mounding may still be considered as an establishment management option to optimise drainage.

Hard rock layers can restrict productivity in drier than average years through a reduction in the volume of soil that be exploited for water. Hard rock layers shallower than 80 cm below the surface can significantly increase the risk of decreased production through insufficient moisture availability in dry years and potential waterlogging in wet years, or following excessive irrigation. Hard rock layers deeper than 80 cm are considered generally suitable, and deeper than 150 cm and suitable.

Organic Carbon, Cation Exchange Capacity and Exchangeable Cations

Organic carbon provides a broad indicator of topsoil fertility in addition to susceptibility of soil structure damage following cultivation. Organic carbon levels can be increased through appropriate land management such as sowing inter-row crops and green manuring. A vegetative cover over the soil surface will be required to protect topsoil structure and minimise wind erosion. Organic carbon levels greater than 1.5 per cent will have reasonable fertility and show fewer topsoil soil structure problems (assuming that the topsoils are not dispersive). Organic carbon levels less than 1.5 per cent are still suitable for apple production but extra attention to fertility and soil structure is required during the plant establishment phase. Minimising tillage and maintaining a good legume based grass cover between the rows will assist in increasing organic carbon levels and soil structure.

Cation Exchange Capacity (CEC) is estimated from measuring the level of the major cations calcium, magnesium, potassium and sodium, and indicates the potential of the soil to hold nutrients. Apples require moderately fertile soils for adequate productivity. CEC levels of greater than 15 have the potential for sustained fertility although a regular and balanced fertiliser programme is still required.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for apples of greater than 80 cm. Apples have a preferred topsoil pH range between 5.0 and 7.5 and subsoils between 6.0 and 7.5 (suitable, class 1). Topsoil pH levels less than 5.0 can be treated with lime and below 4.5 is considered uneconomic, and therefore unsuitable for apple growing. Subsoil pH levels of less than 5.5 are considered unsuitable due to the cost and difficulty of ameliorating subsoil acidity.

Both topsoil and subsoil pH levels greater than 8.0 are considered too alkaline and subject to nutrient imbalance to be suitable for apple growing.

Soil Salinity

Soil salinity levels that may limit production are identified at any depth over the assumed rooting depth for apples of greater than 80 cm. Apples are intolerant of high soil salinity with suitable ECe levels of less than 1.5 dS/m. Soil salinity levels above an ECe of 3.0 dS/m are considered not suitable.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Apples require well drained conditions (suitable, class 1) and can tolerate minor waterlogging that may occur on moderately well drained soils (generally suitable, class 2). Imperfectly drained soils are also generally suitable but are likely to require mounding to improve surface drainage, and treatment of dispersive clay topsoils and subsoils with gypsum. Drainage may also be improved with sub-surface drains (e.g. tile or mole drains). Even with the above treatments, imperfectly drained soils may not be as productive as better drained soils. In considering surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole. Poorly drained soils are likely to have significant crop losses in a majority of years and are therefore classified as unsuitable.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem following summer and autumn rains and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for apple tree use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for apple growing as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for apples only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater

Quality

Irrigation water quality of less than 650 mg/L total dissolved salts (TDS) is considered suitable for irrigating apples, and water quality levels up to 1000 mg/L TDS, generally suitable. At higher salt levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. Water quality levels of greater than 1,000 mg/L TDS are considered unsuitable for irrigating apples even with increased volumes of additional water.

Quantity

Water quantity for irrigation is dictated by evaporative demands and rainfall during the growing season. Available water quantities of greater than 8 ML/ha over the growing season are considered suitable. Water quantities of up to 9.5 ML/ha are generally suitable when water quality is greater than 650 mg/L. Available water quantity levels of less than 8.0 ML/ha are considered unsuitable.

Other Issues

Herbicide drift

Apples are highly susceptible to damage from highly volatile herbicides such as 2,4-D esters. In some cases, herbicides can drift up to 10 km, with the potential for complete or partial defoliation of the orchard if the drift occurs at a critical stage, such as budburst or flowering. Likewise, herbicides used in the orchard should be applied with care, giving due regard to neighbouring properties (people and crops) and wildlife. The type of agricultural enterprises and management in the local area need to be considered prior to orchard establishment.

Pest animal damage

Ringbarking of trees by rabbits and hares can cause significant damage to orchards. Birds can cause significant damage to the crop close to harvest. Bird repellent devices or netting of the apples may be required in some areas.

3.5 Irrigated Vegetable Crops

3.51 Potatoes

Suitability critical values for potato production is presented in Table 3.11.

Climate

Mean January Maximum Temperature

Potatoes are a summer crop that show yield penalties as a result of soil moisture deficits or extended periods of hot weather over 35^{o}C. Mean maximum January temperature is used as a surrogate indicator of the potential for days over 35^{o}C. Below 28^{o}C, relatively few days are above 35^{o}C and areas with this climate are considered suitable. Beyond a mean maximum January temperature of 32^{o}C, the risk of a high number of days with temperatures higher than 35^{o}C is great and although potatoes will grow with very good irrigation management, areas with this climate are considered unsuitable.

Length of Growing Season

Potatoes are highly frost sensitive with a minimum requirement of 120 days without frost. The number of continuous months between October and March that have a mean monthly minimum temperature of greater than 10^{o}C is used as a surrogate for the frost free period. Greater than five months is seen as suitable while less than four months is seen as unsuitable. Areas with greater than five months frost free are suitable for a number of varieties including, ‘French Fry’ chip potatoes such as Russett Burbank. Shorter growing season varieties such as Kennebec are suitable for class 2 areas.

Landscape

Landform

Plains and rises are well suited to potato cropping with respect to machinery access and operation, and irrigation equipment. Low hills are generally suitable but require considered management for machinery access and operation, irrgation equipment, and for surface water run-off control for minimising soil erosion.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for removing vegetative cover and disturbing the soil during autumn means that land with a low water erosion hazard is well suited to potato growing. Surface water control structures such as contour drains may be required in medium water erosion hazard areas. High water erosion areas are generally suited to potato growing if surface water flows can be safely controlled (e.g. contour drains and carefully managed irrigation). The re-establishment of a crop or pasture for the late autumn/winter and spring period should be considered to maintain vegetative cover on all soils.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Potatoes, during their summer growth period, provide good soil protection from wind erosion. Potatoes that are lifted during autumn increase the risk of wind erosion on all soils but particularly on medium to high wind erosion hazard soils. Techniques to minimise the risk of erosion include storing potatoes in the ground until later in the season or establishing tall vegetation around the perimeter of the paddock or irrigation pivot ring to provide shelter and decrease wind speeds. To protect the soil during other periods, the re-establishment of a crop or pasture is required to maintain vegetative cover. If these measures are considered, medium and high soil erosion risk soils are generally suited to potato cropping.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increase the susceptibility of gully erosion. The shallow rooted nature of potato plants, the requirement for irrigation and aggressive soil disturbance involved in seed bed preparation and harvesting makes potato growing unsuited to medium and high gully erosion hazard areas.

Table 3.11. Critical values for determining the suitability for potatoes. Definitions of sub-components are provided in Appendix 2.

	Class 1	**Class 2**	**Class 3**
Climate			
➔Mean January Maximum Temperature (^{o}C)	<28	28 -32	> 32
➔Length of growing season (No. months Mean Monthly Minimum Temperature > 10^{o}C, Oct - Mar))	5	4	0 - 3
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	

➔Wind erosion hazard	LOW	MEDIUM, HIGH	
➔Gully erosion hazard	LOW		MEDIUM, HIGH
➔Rock outcrop (%)	<5	5-10	>10
➔Floaters (%)	<5	5-10	>10
Soil			
➔Topsoil texture	S, SL, L,	CL, LC	MHC
Subsoil texture	L, CL, LC, MHC	S, SL	
➔Topsoil depth (cm) PPF Duplex	>40	25 - 40	<25
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>80	60 - 80	<60
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
➔pH (topsoil or <40 cm)	4.5 - 7.5	<4.5 7.5 - 8.0	>8.0
➔Soil salinity, ECe (dS/m) (to 60 cm)	<1.5	1.5 - 3.0	>3.0
➔Internal drainage * Increase to class 2 if duplex soil with topsoil >45 cm or uniform soil with topsoil >30 cm	WELL	MODERATELY WELL	IMPERFECTLY*, POOR
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS, mg/L)	<1000	1000 - 1300	>1300
Quantity (ML)	>8	>6.5 - 8	<6.5

➔ Primary limitation

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, generally make centre pivot irrigation systems unviable and cause harvesting difficulties. The harvesting of potatoes requires the significant disturbance of the soil. Rock outcrop of greater than ten per cent surface area impedes machine function and increases the risk of harvesting machine damage. Areas with rock outcrop of more than ten per cent of the surface is considered unsuitable.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots, damage cultivation and harvesting equipment, and damages tubers during the harvesting operation. Soil with floaters that occupy more than ten per cent of the top 40 cm is considered unsuitable for potato cropping.

Soil

Soil Texture, Depth and Hard Rock Layers

Potatoes will grow on a wide range of soil textures, but the need to maintain soil structure following sowing and harvesting restricts the soil types available. Stable friable topsoils are important for potato growing to enable unimpeded tuber expansion, provide a suitable seed bed and allow rapid harvesting.

Topsoils with texture classes falling into the sand, sandy loam and loam groups are suitable for potato growing. Soil textures in the clay loam and light clay group are generally suitable if these soils have reasonable structure, however soil structure damage from potato cropping may increase the number of seasons between crops. Medium to heavy clays are considered unsuitable topsoils for potato growing due to the less friable nature of these soils and the risk of excessive soil structure damage.

On class 1 and 2 areas, topsoil structures will require considered management to maintain productivity. Maintenance of topsoil structure through rotating potatoes with other crops or pastures, conservation tillage and maintaining vegetative cover are ways of achieving this aim.

Provided sufficient topsoil exists for adequate cultivation, subsoil texture is relatively unimportant for potatoes. The main limiting factors being heavier subsoils that impede drainage, particularly where they are close to the surface.

Good drainage and a suitable depth of topsoil for cultivation (>25 cm) is critical for potatoes and topsoil depths of greater than 45 cm are considered suitable on duplex soils. Topsoil depths of less than 25 cm are considered unsuitable on duplex soils due to the risk of impeded drainage and perched water and insufficient cultivation depth. Good irrigation management and subsoil amelioration with gypsum (if the clays are dispersive) will allow potatoes to be grown on duplex soils with topsoils of between 25 and 45 cm. Uniform soils of light texture or good structure generally have superior subsoil drainage characteristics as compared to duplex soils. As a result, the depth of topsoil can be shallow for potato growing compared to duplex soils.

Hard rock layers less than 80 cm below the surface can increase the risk of crop failure through potential waterlogging resulting from wet years or following excessive irrigation.

Organic Carbon and Exchangeable Cations

Topsoil organic carbon provides a broad indicator of topsoil fertility in addition to the likely susceptibility to soil structure damage on medium and heavy textures following cultivation. Organic carbon levels can be enhanced through increasing the length of time between successive potato crops, particularly if the intervening land management is pasture or a minimal tilled crop. Potatoes require adequate nutrition for growth and tuber production. Organic carbon levels greater than 1.5 per cent should have reasonable fertility, show fewer topsoil structure problems (assuming that the topsoils are not dispersive), and be more able to withstand the higher cultivation pressures associated with potato production, compared to soils with a lower organic carbon level.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH
Limiting soil pH levels are identified at any depth over the assumed rooting depth for potatoes of 60 cm. The preferred soil pH to 40 cm (suitable, class 1) for potatoes is between 4.5 and 7.5, but pH levels of <4.5 and 7.5 - 8.0 are generally suitable. Soil pH levels of 8.0 and above are considered to be unsuited for potato growing as a result of nutrient deficiencies and imbalances that are difficult to manage. Soil pH levels of less than 6.0, and particularly less than 5.0, are likely to require lime to ameliorate acidity. Applications of lime can promote common scab if seed or machinery are not clear of this disease.

Soil Salinity
Limiting soil salinity levels are identified at any depth over the assumed rooting depth for potatoes of 60 cm. Potatoes are intolerant of high soil salinity levels. ECe levels of up to 1.5 dS/m are considered suitable. Soil salinity levels above an ECe of 3.0 dS/m are considered not suitable for potato growing.

Internal Drainage
Internal drainage is used as an indicator of waterlogging potential. Potatoes require well drained conditions (suitable, class 1) and are intolerant of waterlogged conditions. Moderately well drained soils and imperfectly drained soils that are duplex or uniform with deep topsoils are generally suitable with good irrigation scheduling and management (class 2). Otherwise, imperfectly, poorly and very poorly drained soils are not considered suitable for potato growing.

Surface and/or subsurface drainage or the amelioration of dispersive clay subsoils with gypsum (if the clays are dispersive) can improve both class 1 and class 2 soils. Prior to undertaking surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole.

Topsoil Hydrophobicity
Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem following summer and autumn rains, and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for potato plant use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for potatoes as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for potatoes only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater
Quality
Potatoes are intolerant of high salt levels in irrigation waters. Irrigation water quality of less than 1000 mg/L total dissolved salts (TDS) is considered suitable. Water quality levels up to 1300 mg/L TDS is considered generally suitable. At higher levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. High salt levels enhance cadmium (heavy metal) uptake by tubers. Water

quality levels of greater than 1300 mg/L TDS is considered unsuitable for irrigating potatoes even with increased volumes of additional water.

Quantity

Potatoes are sensitive to water deficits falling below field capacity which can result in reduced yield and mis-shapen tubers. Water quantity for suitable areas for potato growing needs to be 8 ML/ha or greater. Areas that are considered generally suitable can have water quantities as low as 6.5 ML/ha, particularly with shorter season varieties, however a risk of yield loss or poor potato shape will be present in drier years. Areas in the shire with water quantities of less than 6.5 ML/ha are considered unsuitable for potatoes.

3.52 Carrots

Suitability critical values for carrot production are presented in Table 3.12.

Climate

Frost and Temperature

Carrots are tolerant of frost and are suitable for growth in frost susceptible areas. Carrots are less suited to winter growth (April to May plantings) as decreased temperatures slow growth and increase the risk of disease problems. Carrots are suited for growing in all other seasons if adequate irrigation water quality and quantity is available.

Landscape

Landform

Plains and rises are well suited to carrot cropping with respect to machinery access and operation, and irrigation equipment. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control to minimise soil erosion.

Table 3.12. Critical values for determining the suitability for carrots. Definitions of sub-components are provided in Appendix 2.

	Class 1	**Class 2**	**Class 3**
Climate			
Frost risk	LOW, MEDIUM, HIGH		
Landscape			
➔Landform	P, R	LH	H,M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW	MEDIUM, HIGH	
➔Gully erosion hazard	LOW		MEDIUM, HIGH
➔Rock outcrop (%)	<5	5-10	>10
➔Floaters (%)	<5	5-10	>10
Soil			
➔Topsoil texture	S, SL, L,	CL, LC	MHC
Subsoil texture	S, SL, L, CL	LC, MHC	

➔Topsoil depth (cm) PPF Duplex	>45	30 -4 5	<30
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>100	80 - 100	<80
Organic C (%) (topsoil or <30 cm)	>2	<2	
➔pH (topsoil or <45 cm)	5.0-7.5	4.5 - 5.0 7.5 - 8.5	<4.5 >8.5
➔Soil salinity, ECe (dS/m) (to 60 cm)	<1.0	1.0 - 3.0	>3.0
➔Internal drainage * Increase to class 2 if duplex soil with topsoil >45 cm or uniform soil with topsoil >30 cm	WELL	MODERATELY WELL	IMPERFECTLY*, POOR
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS, mg/L)	<700	700 - 1300	>1300
Quantity (ML/ha)	>5	4.5 - 5	<4.5

➔ Primary limitation

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for removing vegetative cover and disturbing the soil during autumn means that land with a low water erosion hazard is well suited to carrot growing. Surface water control structures such as contour drains may be required in medium water erosion hazard areas. High water erosion areas are generally suited to carrot growing if surface water flows can be safely controlled (e.g. using contour drains and carefully managed irrigation). The re-establishment of a crop or pasture for the late autumn/winter and spring period should be considered to maintain vegetative cover on all soils.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Carrots, if grown over the summer/autumn period provide good soil protection from wind erosion. Carrots that are lifted during summer or autumn increase the risk of wind erosion on all soils but particularly on medium to high wind erosion hazard soils. Techniques to minimise the risk of erosion include establishing tall vegetation around the perimeter of the paddock or irrigation pivot ring to provide shelter and decrease wind speeds, and rapidly re-establishing a crop or pasture to provide soil surface protection. To protect the soil during other periods, the re-establishment of a crop or pasture is required to maintain vegetative cover. If these measures are considered, medium and high soil erosion risk soils are generally suited to carrot growing.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increase the susceptibility of gully erosion. The nature of carrot plants, the requirement for irrigation and aggressive soil disturbance involved in seed bed preparation and harvesting makes carrot growing unsuited for medium and high gully erosion hazard areas.

Rock Outcrop and Floaters
Rocks outcropping the soil surface decrease the area of land suitable for cultivation, generally make centre pivot irrigation systems unviable and cause harvesting difficulties. Areas with rocks outcropping more than ten per cent of the surface are considered unsuitable as it increases the risk of harvest machine damage.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots, damage cultivation and harvesting equipment, and damages carrots during the harvesting operation. Soil with floaters that occupy more than ten per cent of the top 40 cm is considered unsuitable for carrot growing.

Soil
Soil Texture, Depth and Hard Rock Layers
Carrots will grow on a wide range of soil textures. However for optimum carrot quality, and the maintenance of soil structure as a result of sowing and harvesting, only a small number of soil textures are suitable. Stable friable topsoils are important to enable unimpeded root growth and expansion, provide a suitable seed bed and allow rapid harvesting.

Topsoils with texture classes falling into the sand, sandy loam and loam groups are suitable for carrot growing. Soil textures in the clay loam and light clay groups are generally suitable however the length and width of the carrot may be impeded if soil structure is not adequate. Carrots grown on clay loams and light clays may require longer periods between cropping to allow soil structure to recover from harvesting induced damage. Medium to heavy clays are considered unsuitable topsoils for carrot growing due to the less friable nature of the soil and the risk of soil structure damage.

On class 1 and 2 areas, topsoil structure will require good management to maintain productivity. Maintenance of topsoil structure through rotating carrots with other crops or pastures, green manuring, conservation tillage and maintaining vegetative cover are ways of achieving this aim.

Provided sufficient topsoil exists for adequate cultivation and root elongation, subsoil texture is relatively unimportant for carrots. The main limiting factors being heavier subsoils that impede drainage, particularly where they are close to the surface.

Good drainage is important for carrots, as well as acceptable depth for root elongation. Suitable topsoil depths for growing premium carrots (medium grade, up to 240 mm long) are greater than 45 cm. Duplex soils are suitable where the topsoil depth is greater than 45 cm and generally suitable (non-premium carrots, baby and small) where the topsoil depth is greater than 30 cm. Duplex soils with topsoil depths of less than

30 cm are considered unsuitable for carrot growing. Good irrigation management, and subsoil amelioration with gypsum (if the clays are dispersive) will allow carrots to be grown on duplex soils with topsoils of between 30 and 45 cm. Uniform soils of light texture or good structure generally have superior subsoil drainage characteristics and root development capabilities as compared to duplex soils. As a result, the depth of topsoil on uniform soils can be shallow for carrot growing compared to duplex soils.

Hard rock layers that are shallower than 80 cm below the surface increase the risk of crop failure through potential waterlogging in wet years or following excessive irrigation.

Organic Carbon and Exchangeable Cations

Topsoil organic carbon provides a broad indicator of topsoil fertility in addition to the likely susceptibility to soil structure damage on medium and heavy textures following cultivation. Organic carbon levels can be increased through increasing the length of time between successive carrot crops particularly if the intervening land management is pasture or a minimal tilled crop. Carrots require adequate nutrition for growth and root elongation. Organic carbon levels greater than 2.0 per cent should have reasonable fertility, show fewer topsoil structure problems (assuming that the topsoils are not dispersive), and be more able to withstand the higher cultivation pressures associated with carrot production, compared to soils with a lower organic carbon level.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for carrots of 60 cm. The preferred soil pH to 45 cm (suitable, class 1) for carrots is between 5.0 and 7.5, but pH levels of between 4.5 - 8.5 are generally suitable. Soil pH levels of less than 6.0 may require lime to ameliorate acidity. Soil pH levels of less than 4.5 can be ameliorated through the addition of lime however this is assumed to be uneconomic particularly if the soil is acid at depth. Soils with a pH of greater than 8.5 are considered unsuitable (class 3) for carrots due to their potential to induce nutrient imbalances.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for carrots of 60 cm. Carrots are very intolerant of high soil salinity levels. ECe levels of less than 1.0 dS/m are considered suitable. Soil salinity levels above an ECe of 3.0 dS/m are considered not suitable for carrot growing.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Carrots require well drained conditions (suitable, class 1) and are intolerant of waterlogged conditions. Moderately well drained soils and imperfectly drained soils that are duplex or uniform with deep topsoils, are generally suitable with good irrigation scheduling and management (class 2). Otherwise, imperfectly and poorly drained soils are not considered suitable for carrot growing.

Surface and/or sub-surface drainage, or the amelioration of dispersive clay subsoils with gypsum (if the clays are dispersive) can improve both class 1 and class 2 soils. Prior to undertaking surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration into the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem following summer and autumn rains, and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for carrot use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for carrots as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for carrots only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater

Quality

Carrots are intolerant of salt levels in irrigation waters. Irrigation water quality of less than 700 mg/L total dissolved salts (TDS) is considered suitable. Water quality levels up to 1300 mg/L TDS are generally suitable. At higher salt levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. Water quality levels greater than 1300 mg/L TDS is considered unsuitable for irrigating carrots even with increased volumes of additional water.

Quantity

Carrots are sensitive to water deficits significantly below field capacity which can result in reduced yield and poor quality carrots. Water quantity for areas suitable for carrot growing needs to be up to 5 ML/ha or greater per crop (summer production). Areas that are considered generally suitable can have water quantities as low as 4.5 ML/ha, particularly with spring or autumn production, however a risk of yield loss or poor carrot quality will be present in drier years. Areas with water quantities of less than 4.5 ML/ha are considered unsuitable for carrots.

Well managed irrigation scheduling is required for carrots over summer to optimise production. Up to three irrigations per day may be required during some periods to minimise soil water deficits.

3.53 Onions

Suitability critical values for onion production are presented in Table 3.13.

Climate

Frost and Temperature

Onions are frost tolerant and are therefore suitable for growing in frost susceptible areas. Onions are suited to growing in all seasons if adequate irrigation water quality and quantity is available.

Landscape

Landform

Plains and rises are well suited to onion growing with respect to machinery access and operation, and irrigation equipment. Low hills are generally suitable but require careful management for machinery access and operation and for surface water run-off control for minimising soil erosion.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for removing vegetative cover and disturbing the soil during autumn means that land with a low water erosion hazard is well suited to onions. Surface water control structures such as contour drains are required in medium water erosion hazard areas. High water erosion hazard land is generally suitable for onions if surface water control measures are employed. The re-establishment of a crop or pasture for the late autumn/winter and spring period is required to maintain vegetative cover on low, medium and high water erosion hazard areas

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Onions, if grown over the summer/autumn period, provide good soil protection from wind erosion. Onions that are lifted during summer or autumn increase the risk of wind erosion on all soils but particularly on medium to high wind erosion hazard soils. Techniques to minimise the risk of erosion include establishing tall vegetation around the perimeter of the paddock or irrigation pivot ring to provide shelter and decrease wind speeds, and rapidly re-establishing a crop or pasture to provide soil surface protection. To protect the soil during other periods, the re-establishment of a crop or pasture is required to maintain vegetative cover. If these measures are considered, medium and high soil erosion risk soils are generally suited to onion growing.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion is initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increases the susceptibility of gully erosion. The shallow nature of onion roots, the requirement for irrigation and aggressive soil disturbance involved in seed bed preparation and harvesting makes onion growing unsuited to medium and high gully erosion hazard areas.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, generally make centre pivot irrigation systems unviable and cause harvesting difficulties. Areas with rocks outcropping more than 10 per cent of the surface are considered unsuitable as it increases the risk of harvesting machine damage.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots, damage cultivation and harvesting equipment, and damages onions during the harvesting operation. Soil with floaters that occupy more than ten per cent of the top 40 cm is considered unsuitable for onions.

Soil

Soil Texture, Depth and Hard Rock Layers

Onions will grow on a wide range of soil textures but for optimum onion size and quality, and the maintenance of soil structure, only a small number of soil textures are suitable. Stable and friable topsoils are important for onion growing to enable unimpeded root growth and bulb expansion, provide a suitable seed bed and allow rapid harvesting.

Table 3.13. Critical values for determining the suitability for onions. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
Frost risk	LOW	MEDIUM, HIGH	
Landscape			
➔Landform	P, R	LH	H, M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW		MEDIUM, HIGH
➔Rock outcrop (%)	<5	5-10	>10
➔Floaters (%)	<5	5-10	>10
Soil			
➔Topsoil texture	SL, CL, L	S, LC	MHC
Subsoil texture	SL,CL,L	S, LC, MHC	
➔Topsoil depth (cm) PPF Duplex	>30	20 - 30	<20
➔Topsoil depth (cm) PPF U	>5	<5	
Depth to hard rock (cm)	>100	80 - 100	>80
Organic C (%) (topsoil or <30 cm)	>2	<2	
➔pH (topsoil or <30 cm)	5.0 - 6.5	4.5 - 5.0 6.5 - 8.0	<4.5 >8.0
➔Soil salinity, ECe (dS/m) (to 50 cm)	<1.2	1.2 - 2.5	>2.5

➔Internal drainage * Increase to class 2 if duplex soil with topsoil >30 cm or uniform soil with topsoil >20 cm	WELL	MODERATELY WELL	IMPERFECTLY*, POOR
➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS, mg/L)	<1000	1000 - 1300	>1300
Quantity (ML/ha/day)	>5	4.5 - 5	<4.5

➔ Primary limitation

Topsoils with texture classes falling into the sandy loam, loam and clay loam groups are suitable for onion growing. Soil textures in the sand group are generally suitable, however the light nature of the soil provides less nutrient holding ability, will result in leaching of nutrients and increases the wind and water erosion hazards. Wind blown sand has the potential to damage young onion plants. Light clays are generally suitable but are likely to require greater management to control soil structure decline. The period between successive onion crops may need to be increased on light clay soils. Medium to heavy clays are considered unsuitable for onion growing due to their generally less friable nature and potential soil structure problems.

On class 1 and 2 areas, topsoil structure will require good management to maintain productivity. Maintenance of topsoil structure through rotating onions with other crops or pastures, green manuring, conservation tillage and maintaining vegetative cover are ways of achieving this aim.
Provided sufficient topsoil exists for adequate cultivation and bulb expansion, subsoil texture is relatively unimportant for onions. The main limiting factors being heavier subsoils that impede drainage, particularly where they are close to the surface.

Good drainage is important for onions in addition to acceptable depth for root growth. Duplex soils with topsoil depths of greater than 30 cm are considered suitable, while topsoil depths of less than 20 cm are considered unsuitable. Good irrigation management, and subsoil amelioration with gypsum (if the clays are dispersive) will allow onions to be grown on duplex soils with topsoils of between 20 and 30 cm. Uniform soils of light texture or good structure generally have superior subsoil drainage characteristics and root development capabilities as compared to duplex soils. As a result, the depth of topsoil on uniform soils can be shallower for onion growing as compared to duplex soils.

Hard rock that are shallower than 80 cm below the surface increase the risk of crop failure through potential waterlogging as a result of wet years or following excessive irrigation.

Organic Carbon and Exchangeable Cations

Topsoil organic carbon provides a broad indicator of topsoil fertility, in addition to the likely susceptibility to soil structure damage on medium and heavy textures following cultivation. Organic carbon levels can be increased through increasing the length of time between successive onion crops particularly if the intervening land management is pasture or a well managed crop. Onions require adequate nutrition for growth and root elongation. Organic carbon levels of greater than 2.0 per cent should have reasonable fertility, show fewer topsoil structure problems (assuming that the topsoils are not dispersive), and be more able to withstand the higher cultivation pressures associated with onion production, as compared to soils with a lower organic carbon level.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for onions of 50 cm. The preferred soil pH to 30 cm (suitable, class 1) for onions is between 5.0 and 6.5, pH levels of between 4.5 and 8.0 are considered generally suitable. Soil pH levels of less than 5.0 may require lime to ameliorate acidity. Topsoil pH levels of less than 4.5 can be ameliorated through the addition of lime, but high and impractical quantities would be required particularly if the soils are acid at depth. Soils with a pH of greater than 8.0 are considered unsuitable (class 3) for onions due difficulties in ameliorating potential nutrient imbalances.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for onions of 50 cm. Onions are intolerant of high soil salinity levels. ECe levels of less than 1.2 dS/m are considered suitable. Soil salinity levels above an ECe of 2.5 dS/m are considered not suitable for onion growing.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Onions require well drained conditions (suitable, class 1) and are generally intolerant of waterlogged conditions. Moderately well drained soils and imperfectly drained soils that are duplex or uniform with deeper topsoils, are generally suitable with good irrigation scheduling and management (class 2). Otherwise, imperfectly, and poorly drained soils are not considered suitable for onion growing.

Surface and/or sub-surface drainage or the amelioration of dispersive clay subsoils with gypsum (if the clays are dispersive) can improve both class 1 and class 2 soils. Prior to undertaking surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem following summer and autumn rains, and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for onion use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for onions as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for onions only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater

Quality

Onions are moderately intolerant of salt levels in irrigation waters. Irrigation water quality of less than 1000 mg/L total dissolved salts (TDS) is considered suitable. Water quality levels up to 1300 mg/L TDS are considered generally suitable. At higher salt levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. Water quality levels greater than 1300 mg/L TDS is considered unsuitable for irrigating onions even with increased volumes of additional water.

Quantity

Onions are sensitive to water deficits below field capacity which can result in reduced yield and poor quality. Water quantity for suitable areas for onion growing needs to be up to 5 ML/ha or greater per crop (summer production). Areas that are generally suitable can have water quantities as low as 4.5 ML/ha, particularly with spring or autumn production, however a risk of yield loss or poor onion quality will be increase in drier years. Areas with water quantities of less than 4.5 ML/ha are considered unsuitable.

3.54 Sweet corn

Suitability critical values for sweet corn production are presented in Table 3.14.

Climate

Mean Monthly Temperature

Sweet corn is a summer growing crop that requires mean monthly temperatures (October to March) of between 16 and 24^{o}C for optimum growth and cob quality (Dimsey, 1995). Suitable areas should have a mean monthly temperature of 18-22^{o}C between October and March, while generally suitable areas should have a mean monthly temperature of between 16 -17 and 23-24^{o} C between October and March.

Length of Growing Season

Sweet corn is a highly frost sensitive plant with a requirement for a minimum of 120 days without frost. The number of continuous months between October and March that have a mean monthly minimum temperature of greater than 10^{o}C is used as a surrogate for the frost free period. Greater than five months is seen as suitable while less than four months is seen as unsuitable. Shorter growing season varieties of sweet corn may be required for class 2 areas.

Mean Maximum January Temperature

Sweet corn will show yield penalties as a result of soil moisture deficits or periods of hot windy weather during the silking stage. Mean maximum January temperature is used as a surrogate indicator of the potential for hot days during the silking period (generally January to February). Below $30^{o}C$, the number of excessively hot days is limited and is suitable for sweet corn production. Above a mean maximum January temperature of $32^{o}C$, the risk of a high number of excessively hot days is likely to be high, and areas with this climate are considered unsuitable for sweet corn production.

Landscape

Landform

Plains and rises are well suited to sweet corn production with respect to machinery access and operation, and irrigation equipment. Low hills are generally suitable but require considered management for machinery access and operation and for surface water run-off control for minimising soil erosion.

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The requirement for cultivation and potential for removing vegetative cover and disturbing the soil during autumn means that land with a low water erosion hazard is well suited to sweet corn growing. Surface water control structures such as contour drains are required in medium water erosion hazard areas. High water erosion hazard is generally suitable for sweet corn if surface water control measures are employed. The re-establishment of a crop or pasture for the late autumn winter and spring period is required to maintain vegetative cover on low, medium and high water erosion hazard areas.

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Sweet corn, during the summer growth period, provides good soil protection against wind erosion. Provided that stubbles are retained following harvesting, and conservation tillage practices are utilised for establishment of the following crop, sweet corn is well suited to growing on soils with medium to high wind erosion hazard. To protect the soil during other periods of the year, the re-establishment of a crop or pasture is required to maintain vegetative cover.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increase the susceptibility of gully erosion. The deeper rooted nature of sweet corn makes the crop suitable for medium gully erosion hazard areas with careful irrigation scheduling and management. High gully erosion hazard areas are considered unsuitable for irrigated sweet corn production due to the difficulty of controlling irrigation drainage within the soil profile.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation, generally make centre pivot irrigation systems unviable and cause harvesting difficulties. Rock outcrops of greater than 10 per cent surface area impede machinery function. Areas with rocks outcropping more than 10 per cent of the surface are considered unsuitable for irrigated sweet corn production.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damage cultivation equipment. Soil with floaters that occupy more than 10 per cent of the topsoil is considered unsuitable for sweet corn production.

Table 3.14. Critical values for determining the suitability for sweet corn. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Mean Monthly Temperature (^oC) (Oct - Mar)	18 -22	16 - 17 23 - 24	<16 >24
➔Length of growing season (No. months with Mean Monthly Minimum Temperature > 10^oC, Oct - Mar))	5	4	<4
➔Mean Maximum January (^oC)	<30	30 - 32	>32
Landscape			
➔Landform	P,R	LH	H, M
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM	HIGH
➔Rock outcrop (%)	<10	10 - 20	>20
➔Floaters (%)	<10	10 - 20	>20
Soil			
➔Topsoil texture	CL, L, LC	SL, MHC	S
Subsoil texture	CL, L, LC, MHC		SL, S
➔Topsoil depth (cm) PPF Duplex	>25	15 - 25	<15
➔Topsoil depth (cm) PPF U	>10	<10	
Depth to hard rock (cm)	>100	80 - 100	<80
Organic C (%) (topsoil or <30 cm)	>1.5	<1.5	
➔pH (topsoil or <40 cm)	5.0 - 8.0	4.5 - 5.0 >8.0	<4.5
➔Soil salinity, ECe (dS/m) (to 60 cm)	<2.0	2.0 - 4.0	>4.0
➔Internal drainage * Increase to class 2 if duplex soil with topsoil >25 cm or uniform soil with topsoil >15 cm	WELL	MODERATELY WELL	IMPERFECTLY*, POORLY

➔Hydrophobicity	NO	YES	
Groundwater			
Quality (TDS mg/L)	<500	500 - 1500	>1500
Quantity (ML/ha)	>8	6.5 - 8	<6.5

➔ Primary limitation

Soil

Soil Texture, Depth and Hard Rock Layers

Sweet corn will grow on a range of soil textures but prefers topsoil textures in the clay loam, loam and light clay groups. Sandy loams and medium heavy clays are considered generally suitable, but sands are considered unsuitable due to poor nutrient and water holding capacities. All texture classes are suitable for subsoils apart from soils in the sands group, which are unsuitable. Lighter textured subsoils exacerbate the poor fertility and nutrient leaching problems of sandy topsoils.

Good drainage is important for sweet corn in addition to an acceptable topsoil depth for root growth. Duplex soils with topsoil depths greater than 25 cm are considered suitable for sweet corn while topsoil depths less than 15 cm on duplex soils are considered unsuitable due to potential waterlogging problems and impeded root development. Good irrigation management, and subsoil amelioration with gypsum (if the clays are dispersive) will allow sweet corn to be grown on duplex soils with topsoils of between 15 - 25 cm. Uniform soils of light texture or good structure generally have superior subsoil drainage characteristics and root development capabilities as compared to duplex soils. As a result, the depth of topsoil on uniform soils can be shallower compared to duplex soils.

Hard rock layers shallower than 100 cm below the surface increase the risk of crop failure through potential waterlogging as a result of wet years or following excessive irrigation.

Organic Carbon and Exchangeable Cations

Organic carbon provides a broad indicator of topsoil fertility in addition to the likely susceptibility of soil structure decline following cultivation. Organic carbon levels can be increased through appropriate land management such as stubble retention and minimum tillage or direct drilling. Sweet corn requires good nutrition for growth and root development. Organic carbon levels greater than 1.5 per cent should have reasonable fertility and show fewer topsoil structure problems (assuming that the topsoils are not dispersive). Organic carbon levels less than 1.5 per cent are considered to be only generally suitable for sweet corn production due to poorer fertility and structure, particularly on the heavier soil textures (clay loams and clays).

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for sweet corn of 100 cm. The preferred soil pH to 40 cm (suitable, class 1) for sweet corn is between 5.0 and 8.0, and pH levels between 4.5 and greater than 8.0 are considered generally suitable. Topsoil pH levels less than 6.0 may require lime to ameliorate acidity. Topsoil pH levels less than 4.5 can be ameliorated through the addition of lime but high and impractical quantities would be required particularly if the acidity is at depth. Soils with a pH less than 4.5 are considered unsuitable (class 3) for sweet corn.

Soil Salinity

Limiting soil salinity levels are identified at any depth over the assumed rooting depth for sweet corn of 100 cm. Sweet corn is moderately intolerant of high soil salinity levels. ECe levels of less than 2.0 dS/m are considered suitable. Soil salinity levels above an ECe of 4.0 dS/m are considered unsuitable for sweet corn growing.

Internal Drainage

Internal drainage is used as an indicator of waterlogging potential. Sweet corn requires well drained conditions (suitable, class 1) and are generally intolerant of waterlogged conditions. Moderately well drained soils and imperfectly drained soils that are duplex or uniform with deeper topsoils, are generally suitable with good irrigation scheduling and management (class 2). Otherwise, imperfectly and poorly drained soils are not considered suitable for sweet corn growing.

Surface and/or sub-surface drainage or the amelioration of dispersive clay subsoils with gypsum (if the clays are dispersive) can improve both class 1 and class 2 soils. Prior to undertaking surface or sub-surface drainage, the fate of the drained water needs to be considered with respect to neighbouring properties and the catchment as a whole.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration to the soil profile when soils are being wet up from the dry state. Hydrophobicity is a problem following summer and autumn rains, and spray and drip irrigation systems that apply water to dry soils. The result is decreased water available for sweet corn use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for sweet corn as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for sweet corn only following amelioration of the hydrophobicity. The addition of clay to the topsoil (claying) is proving to be highly effective in reducing hydrophobicity and is now seen as a realistic management option.

Groundwater

Quality

Sweet corn is intolerant of salt levels in irrigation waters. Irrigation water quality of less than 500 mg/L total dissolved salts (TDS) is considered suitable, and water quality levels up to 1500 mg/L TDS generally suitable. At higher levels, up to 15 per cent extra water may need to be applied to leach accumulated salts in the soil profile. Water quality levels of greater than 1500 mg/L TDS is considered unsuitable for irrigating sweet corn even with increased volumes of additional water.

Quantity
Sweet corn is sensitive to water deficits throughout most of the growing season which can result in reduced yield and cob fill. Water quantity for suitable areas for sweet corn growing needs to be 8 ML/ha or greater. Areas are considered generally suitable with water quantities as low as 6.5 ML/ha, particularly with shorter season varieties, however a risk of yield and/or quality loss will be present in drier years. Areas with water quantities of less than 6.5 ML/ha are considered unsuitable for sweet corn.

3.6 Dryland Forestry

3.61 Radiata Pine (*Pinus radiata*)
Suitability critical values for radiata pine are presented in Table 3.15.

Climate
Rainfall
Radiata pine plantations for timber production require high rainfall to be commercially viable. Average annual rainfall of greater than 700 mm is suitable while areas with rainfall between 650 and 700 mm are generally suitable although growth rates are likely to be slower. Areas with annual average rainfall of less than 650 mm are considered unsuitable for radiata pine.

Mean Maximum January Temperature
Cool to moderately warm areas are suited to the growth of radiata pine. Mean maximum January temperature (MMJT) is used as an estimate of excessive temperature. Suitable areas have a MMJT of less than 28^{o}C, while areas have a MMJT of between 28 and 30^{o}C are generally suitable. Areas with MMJT of higher than 30^{o}C are considered unsuitable.

Landscape
Landform
Plains, rises and low hills are well suited to commercial forestry with respect to machinery access and operation. Hills and mountains are generally suitable but require careful management for machinery access and operation and for surface water run-off control for minimising soil erosion.

Water Erosion Hazard
Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The lower intensity of impact associated with commercial forestry makes this land use suitable for low water erosion hazard soils and generally suitable for medium and high water erosion hazard soils. Careful management is required during establishment and harvesting on medium and high water erosion hazard soils to minimise the risk of erosion associated with machine traffic, snig tracks and log landings. The Victorian Code of Forest Practices for Timber Production provides guidelines to minimise water erosion during establishment and harvesting.

Table 3.15. Critical values for determining the suitability for radiata pine. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall (mm)	>700	650-700	<650
Mean Maximum January Temperature (^oC)	<28	28-30	>30
Landscape			
➔Landform	P, R,LH	H,M	
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM, HIGH	
➔Rock outcrop (%)	<20	>20	
➔Floaters (%)	<30	>30	
Soil			
➔Subsoil texture	L, CL, LC	S, SL, MHC	
Topsoil depth (cm)	>20	<20	
➔Depth to hard rock (cm)	>300	150 - 300	<150
➔pH (subsoil or >30 cm)	5.5-7.5	4.5-5.5 7.5-8.0	<4.5 >8.0
➔Soil salinity, ECe (dS/m)	<2.0	2.0 - 4.0	>4.0
➔Internal drainage	WELL, MODERATELY WELL	IMPERFECTLY	POORLY
Hydrophobicity	NO	YES	

➔ Primary limitation

Wind Erosion Hazard

Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Commercial forestry is a good land use for medium and high wind erosion hazard soils. Vegetative cover of the soil is present throughout the rotation which significantly minimises the risk of wind erosion. Care in managing high wind erosion hazard soils is required following harvesting. Operations, such as windrowing of harvest trash, need to consider the amount of soil being exposed without protective vegetative cover. Closer windrows, perpendicular to the prevailing summer winds, will provide a good level of protection in these circumstances.

Gully Erosion Hazard

Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increase the susceptibility of gully erosion. Tree roots are able to stabilise subsoils and utilise excess water within the soil profile. Establishment and harvesting will create management difficulties in areas with medium to high gully erosion hazard, particularly with the concentration of surface water flowing from snig tracks and log landings. Careful control of surface water and rapid reaforestation will minimise this risk. The Victorian Code of Forest Practices for Timber Production provides guidelines.

Rock Outcrop and Floaters

Rocks outcropping the soil surface decrease the area of land suitable for cultivation and create establishment and harvesting difficulties. Rock outcrops less than 20 per cent are considered suitable while areas with outcrops greater than 20 per cent are only generally suitable. The type of machinery utilised in forestry establishment and harvesting are capable of handling rock outcrops and therefore no upper limit is provided.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damage cultivation equipment. The deep rooted nature of trees reduce the impact of floaters, making areas with up to 30 per cent floating stone suitable. Areas with higher levels (>30 per cent) are generally suitable but are likely to slow growth rates or decrease the stocking rate of the site.

Soil

Soil Texture, Depth, Exchangeable Cations and Hard Rock Layers

Topsoil texture is not relevant to tree production apart from during the establishment phase. Topsoil depth is important from a drainage point during the establishment phase. Topsoil depths greater than 20 cm are suitable while shallower topsoils are only generally suitable.

Radiata pine will grow in a wide range of subsoil textures with a preference towards heavier textures that provide greater water and nutrient holding capacities. Textures in the sands and sandy loam groups are generally suitable, however trees are likely to show poorer performance due to water and nutrient holding problems. Medium to heavy clay textured subsoils may create root penetration difficulties if they are sodic. In these circumstances, deep ripping with gypsum may increase the rate of root exploration of the subsoil.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Hard rock layers that are shallower than 150 cm below the surface decrease the volume of soil that can be exploited by the tree roots and increase the risk of stress during drier years. Tree stress will result in a greater susceptibility to disease or in some cases, mortality. Ideally, soils should be deeper than 200 cm and preferably deeper than 300 cm.

Soil pH
Limiting soil pH levels are identified at any depth over the assumed rooting depth for radiata pine of greater than one metre. The preferred soil pH (suitable, class 1) for radiata pine is between 5.5 and 7.5 but pH levels between 4.5 and 8.0 are generally suitable. Soils with a pH less than 4.5 are considered unsuitable (class 3) for Radiata pine due to the difficulty in ameliorating subsoil acidity. Soils with a pH greater than 8.0 are also considered unsuitable due to the potential for nutrient imbalances.

Soil Salinity
Radiata pine is intolerant of high soil salinity levels. ECe levels of less than 2.0 dS/m are suitable while levels above 4.0 dS/m are unsuitable.

Internal Drainage
Internal drainage is used as an indication of waterlogging potential. Radiata pine is tolerant of small periods of waterlogging. Imperfectly drained soils are generally suitable for Radiata pine while poorly drained soils are unsuited.

Topsoil Hydrophobicity
Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration into the soil profile when soils are being wet up from the dry state (summer and autumn break rains). The result is decreased water available for tree use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for tree growing as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for tree growing but management to minimise soil erosion may be required.

3.62 Blue Gum (*Eucalyptus globulus*)
Suitability critical values for blue gum are presented in Table 3.16.

Climate
Rainfall
Blue gum plantations for timber production require high rainfall to be commercially viable. Average annual rainfall totals of greater than 700 mm are suitable while areas with rainfall between 650 and 700 mm are generally suitable although growth rates are likely to be slower. Areas with annual average rainfall levels of less than 650 mm are considered unsuitable for Blue gum.

Mean Maximum January Temperature
Cool to moderately warm areas are suited to the growth of Blue gum. Mean maximum January temperature (MMJT) is used as an estimate of excessive temperature. Suitable areas have a MMJT of less than 28^{o}C, while generally suitable areas have a MMJT of between 28 and 30^{o}C. Areas with MMJT of higher than 30^{o}C are considered unsuitable.

Landscape

Landform

Plains, rises and low hills are well suited to commercial forestry with respect to machinery access and operation. Hills and mountains are generally suitable but require careful management for machinery access and operation and for surface water run-off control for minimising soil erosion.

Table 3.16. Critical values for determining the suitability for blue gum. Definitions of sub-components are provided in Appendix 2.

	Class 1	Class 2	Class 3
Climate			
➔Rainfall (mm)	>700	650-700	<650
Mean Maximum January Temperature (^oC)	<28	28 - 30	>30
Landscape			
➔Landform	P, R, LH	H, M	
➔Water erosion hazard	LOW, MEDIUM	HIGH	
➔Wind erosion hazard	LOW, MEDIUM	HIGH	
➔Gully erosion hazard	LOW	MEDIUM, HIGH	
➔Rock outcrop (%)	<10	10-25	>25
➔Floaters (%)	<10	10-25	>25
Soil			
➔Subsoil texture	L, CL, LC	S, SL, MHC	
Topsoil depth (cm)	>20	<20	
➔Depth to hard rock (cm)	>300	150 - 300	<150
➔pH (subsoil or >30 cm)	5.5-7.5	5.0 - 5.5 7.5 - 8.0	<5.0 >8.0
➔Soil salinity, ECe (dS/m)	<4.0	4.0 - 6.0	>6.0
➔Internal drainage	WELL, MODERATELY WELL	IMPERFECTLY	POORLY
Hydrophobicity	NO	YES	

➔ Primary limitations

Water Erosion Hazard

Water erosion hazard is determined from soil texture, soil structure, dispersibility of the clay, the hydrophobicity of sandy topsoils and slope of the land. The lower intensity of impact associated with commercial forestry makes this land use suitable for low water erosion hazard soils and generally suitable for medium and high water erosion hazard soils. Careful management is required during establishment and harvesting on medium and high water erosion hazard soils to minimise the risk of erosion associated with machine traffic, snig tracks and log landings. The Victorian Code of Forest Practices for Timber Production provides guidelines to minimise water erosion during establishment and harvesting.

Wind Erosion Hazard
Wind erosion hazard is determined from soil texture, soil structure and organic matter levels. Commercial forestry is a good land use for medium and high wind erosion hazard soils. Vegetative cover of the soil is present throughout the rotation which significantly minimises the risk of wind erosion. Care in managing high wind erosion hazard soils is required following harvesting. Operations, such as windrowing of harvest trash, need to consider the amount of soil being exposed without protective vegetative cover. Closer windrows, perpendicular to the prevailing summer winds, will provide a good level of protection in these circumstances.

Gully Erosion Hazard
Gully erosion hazard is determined from subsoil structure, subsoil clay dispersibility and slope. Gully erosion can be initiated by excess water flowing laterally through the subsoil and transporting dispersive clays. Slope, soil disturbance and unused excess water in the soil profile are major factors that increase the susceptibility of gully erosion. Tree roots are able to stabilise subsoils and utilise excess water within the soil profile. Establishment and harvesting will create management difficulties in areas with medium to high gully erosion hazard, particularly with the concentration of surface water flowing from snig tracks and log landings. Careful control of surface water and rapid reaforestation will minimise this risk. The Victorian Code of Forest Practices for Timber Production provides guidelines.

Rock Outcrop and Floaters
Rocks outcropping the soil surface decrease the area of land suitable for cultivation and create establishment and harvesting difficulties. Rock outcrops less than 20 per cent are considered suitable while areas with outcrops greater than 20 per cent are only generally suitable. The type of machinery utilised in forestry establishment and harvesting are capable of handling rock outcrops and therefore no upper limit is provided.

Rock floaters (rocks within the profile) reduce the volume of soil able to be exploited by plant roots and also damage cultivation equipment. The deep rooted nature of trees reduce the impact of floaters, making areas with up to 30 per cent floating stone suitable. Areas with higher levels (>30 per cent) are generally suitable but are likely to slow growth rates or decrease the stocking rate of the site.

Soil
Soil Texture, Depth, Exchangeable Cations and Hard Rock Layers
Topsoil texture is not relevant to tree production apart from during the establishment phase. Topsoil depth is important from a drainage point during the establishment phase. Topsoil depths of greater than 20 cm are suitable while shallower topsoils are only generally suitable.

Blue gum will grow in a wide range of subsoil textures with a preference towards heavier textures that provide greater water and nutrient holding capacities. Textures in the sands and sandy loam groups are generally suitable, however trees are likely to show poorer performance due to water and nutrient holding problems. Medium to heavy clay textured subsoils may create root penetration difficulties if they are sodic.

In these circumstances, deep ripping with gypsum may increase the rate of root exploration of the subsoil.

Clay soils that are sodic (exchangeable sodium/CEC of greater than 6), or have high exchangeable magnesium (exchangeable calcium/exchangeable magnesium ratio of less than 2), are likely to be poorly structured. These soils tend to disperse on wetting, causing the soil structure to deteriorate. Impeded drainage and poor root growth is likely to result. Gypsum can ameliorate sodic and high exchangeable magnesium soils, although getting gypsum to depth for poorly structured subsoils can be a costly and often impractical task.

Hard rock layers that are shallower than 150 cm below the surface decrease the volume of soil that can be exploited by the tree roots and increase the risk of stress during drier years. Tree stress will result in a greater susceptibility to disease or in some cases, mortality. Ideally, soils should be deeper than 200 cm and preferably deeper than 300 cm.

Soil pH

Limiting soil pH levels are identified at any depth over the assumed rooting depth for Blue gum of greater than 1 m. The preferred soil pH (suitable, class 1) for Blue gum is between 5.5 and 7.5 but pH levels between 4.5 and 8.0 are generally suitable. Soils with a pH of less than 4.5 are considered unsuitable (class 3) for blue gum due to the difficulty in ameliorating subsoil acidity. Soils with a pH greater than 8.0 are also considered unsuitable due to the potential for nutrient imbalances.

Soil Salinity

Blue gum in intolerant of high soil salinity levels. ECe levels of less than 2.0 dS/m are suitable while levels above 4.0 dS/m are unsuitable.

Internal Drainage

Internal drainage is used as an indication of waterlogging potential. Blue gum is tolerant of small periods of waterlogging. Imperfectly drained soils are generally suitable for Blue gum while poorly drained soils are unsuited.

Topsoil Hydrophobicity

Hydrophobicity (water repellence or non-wetting soils) is a characteristic of sandy soils that decreases water infiltration into the soil profile when soils are being wet up from the dry state (summer and autumn break rains). The result is decreased water available for tree use and surface water run-off that increases the risk of soil erosion. Topsoils that are not hydrophobic are suitable for tree growing as water infiltration is likely to be adequate. Topsoils that are hydrophobic are generally suitable for tree growing but management to minimise soil erosion may be required.

Chapter 4
GROUNDWATER AND SALINITY

4.1 Background

Two basins underlie the West Wimmera Shire, the Murray Basin to the north and west and the Otway Basin to the south east. Three main aquifers occur within these basins. The Pliocene Sands Aquifer (Parilla Sands of the Murray Basin) overlies the mid to late Tertiary Limestone Aquifer (Murray Group Limestone Aquifer of the Murray Basin and Heytesbury Group Limestone of the Otway Basin), which in turn overlies the lower Tertiary Sand Aquifer (Renmark Group of the Murray Basin and Wangerrip Group of the Otway Basin). Of these aquifers, the Parilla Sands, Murray Group and the Renmark Group are the most important with respect to water exploitation for irrigation.

Virtually all groundwater is ultimately derived, directly or indirectly, from rainfall. Groundwater flow direction of these aquifers depends on the basin; to the NNW for the Murray Basin aquifers and to the SW for Otway Basin aquifers.

A layer of impermeable clay acts as an aquitard between the Parilla Sands Aquifer and the Murray Group Aquifer. The distribution and thickness of the clay varies throughout the shire (Bradley, et al., 1995), with some potential for downward leakage from the Parilla Sands Aquifer to the Murray Group Aquifer. The Parilla Sands Aquifer is generally only saturated in the western limits of the shire and the water level gradually decreases at the eastern side of the shire. At the Otway-Murray Basin divide, the Parilla Sands Aquifer is also saturated; this area has the shallowest watertable in the West Wimmera Shire.

Land within 20 kilometres of the Victorian/South Australian Border is covered by the Victorian-South Australian Border Agreement. This border agreement zone has been established to avoid deleterious effects occasioned by present and future large-scale groundwater withdrawals on the State border of South Australia and Victoria (Stradter and Stewart, 1990). Considerable hydrogeological investigations have been undertaken in this zone, for example Stradter and Stewart (1990), Bradley, et al. (1995), Sibenaler and Stradter (1989), Dudding (1990). Some specific hydrogeological assumptions of this section rely on information deduced from the border zone agreement.

4.2 Murray Basin Aquifers

4.2.1 Parilla Sands Aquifer

Groundwater Quality and Quantity

In general, the Parilla Sands Aquifer is the uppermost saturated layer within the shire. Groundwater quality is the greatest restraint for utilising the water from this aquifer. Aquifer salinities within the shire generally increases from east to west, ranging from 450 mg/l to 7700 mg/l respectively. The higher groundwater salinities experienced in the eastern region of the aquifer is associated with low rainfall and soils that allow relatively high recharge.

Recharge and discharge processes

Recharge to the Parilla Sands Aquifer is a regional process, with some point sources. Point sources of recharge to the aquifer include lake systems that are perched above the watertable and the seasonal recharge of groundwater discharge lakes. In general, the watertable is relatively flat and discharges where the ground surface intersects with the watertable (topographically low areas).

Groundwater trends
Water level information within the study area, particularly in the Edenhope region of the basin, suggests a rising trend in the groundwater level. Hocking (1996) analysed a representative piezometer of the area and concluded a rise of 4 cm/year for the past fifteen years. Basin wide groundwater levels of the Parilla Sands Aquifer shows a slight rise in water level.

Currently, there are few irrigated areas within the shire that overly the Parilla Sands Aquifer. If the area of land under irrigation increased, it would be expected that the increase in recharge would raise the water level and aquifer salinity in the long term. This potentially has consequences with respect to salinity on the viability of the irrigation area and also local dryland areas.

Depth to water table within the shire varies. Depth to Parilla Sand water tables varies from two to 30 metres, which depends on slope position and locality within the shire. In general, depth to Parilla Sands Aquifer is greatest to the east and decreases to the west, with the shallowest water tables occurring south of Edenhope.

Bore yields
Aquifer yields of the Parilla Sand range from less than 0.5 - 5 l/s, with the majority of the shire having salinity yields ranging between 0.5 - 5 l/s (Mc Auley et al., 1992; Robinson et al., 1992; Mann et al., 1994).

4.2.2 Murray Group Aquifer
Groundwater Depth, Quality and Quantity
The Murray Group Aquifer is the most valuable groundwater resource within the West Wimmera Shire. The relatively shallow depth of this aquifer allows inexpensive groundwater extraction and drilling. Water quantity yields, throughout the study area, are relatively high and salinity low. Current Permissible Annual Volumes (PAV) and recommended PAV groundwater extraction rates in the Victorian-South Australian Border Zone are shown in Table 4.1.

Table 4.1 Current and recommended PAVs based on the five-year technical review (source Bradley et al., 1995).

Zone	Current PAV (ML/year)	Recommended PAV (ML/year)
3B	16,500	16,500
4B	14,000	14,000
5B	18,500	8,100
6B	6,000	3,600
7B	7,000	7,100
8B	3,500	3,600

Table 4.1 shows current PAV are recommended to decrease in zones 4B and 5B, with zones 7B and 8B recommended to have an increase in PAV.

The potentiometric surface of the Murray Group Limestone ranges between approximately 60 - 90 metres below ground surface throughout the study area, with a decrease in the potentiometric surface depth in a north-west direction.

Excessive groundwater pumping can induce lateral and/or vertical migration of higher salinity water into the pumped aquifer (Bradley et al., 1995). Dudding (1990) suggests the most sensitive parameter controlling groundwater salinity changes is the volume of groundwater extraction.

A PAV increase of five times would increase groundwater salinity by one or two fold over 100 years, with a linear rise after the first ten years of pumping (Dudding, 1990). Zones 4B, 5B and 6B all show an increase in groundwater salinity ranging from 3 to 150 mg/l/annum (Bradley, et al., 1995), which is associated with rising groundwater levels and/or the recent clearance of native vegetation.

Recharge/Discharge
Recharge to the Murray Group Limestone occurs by two general processes, point source and diffuse recharge. Point source recharge in the West Wimmera occurs in a few areas (more common to the west), such as runaway holes and drainage wells. Diffuse recharge of the unconfined or semi-unconfined part of the aquifer is controlled by rainfall. Where the aquifer is semi-unconfined (generally east of Kaniva), some downward leakage by the overlying Parilla Sands Aquifer exists. Diffuse recharge is currently considered to be the dominate recharge source for this aquifer.

Groundwater trends
Within the Victorian-South Australian Border Groundwater Agreement Zone, the permissible average annual rate of decline of the potentiometric surface is to be no greater than 0.05 m for all zones. Currently, water level data suggests the potentiometric surface is relatively stable.

Bore Yields
Aquifer yields in this system range from < 0.5 - >50 l/s. The majority of the shire has aquifer yields ranging from 5 - 50 l/s (Mc Auley et al., 1992; Robinson et al., 1992; Mann et al., 1994).

4.2.3 Renmark Group

Groundwater Depth, Quality and Quantity
Currently, the Renmark Group is not regarded as an important groundwater resource because better quality water is available in the overlying Murray Group Limestone Aquifer (Bradley et al., 1995). It is also less developed as a groundwater resource because of the higher drilling and pumping costs associated with its depth. As a consequence, hydraulic data for this aquifer is sparse. As the Permissible Annual Volumes (PAV) for the Murray Group Limestone Aquifer are reached within the Victorian-South Australian Border Agreement Zone, more attention is being placed upon this aquifer. The best quality groundwater runs in a thick south west orientated strip from Nhill to Apsley.

Estimations for groundwater through-flow into the Victorian-South Australian Border Agreement Zone eastern boundary have been made by Bradley et al., (1995),and are presented in Table 4.2.

Table 4.2 Estimates of groundwater through-flow for the Renmark Group (Bradley et al., 1995), for the Victorian-South Australian Border Agreement Zone.

Zone	Groundwater inflow at eastern boundary (ML/YEAR)
3B	8,000
4B	16,000
5B	32,000
6B	8,000
7B	8,000
8B	4,000

These through-flow rates suggest significant un-utilised groundwater passes under the shire each year and may be an appropriate source of groundwater. Bradley et al. (1995) goes further and suggests the Renmark Group can provide an alternate groundwater resource to that of the Murray

Group Limestone Aquifer.

Recharge/Discharge
Water entering the aquifer is believed to occur on a wide strip from an area east of Kaniva across to the Wimmera Trench. Downward leakage of groundwater to the Renmark Group is restricted by the Ettrick Formation and Geera Clay. Together the Ettrick Formation, Geera Clay and a low hydraulic gradient lowers the potential of recharge into the aquifer. Currently, there has been no investigation on inter-aquifer downward leakage into the Renmark Group. Assessments of inter-aquifer leakage into the Renmark Group is likely to be provided in the next five year technical work plan of the Victorian-South Australian Border Agreement Zone.

Groundwater trends
The South Australian Border Agreement Zone Review Committee have recognised the potential of this aquifer and initiated some water chemistry monitoring programs in 1984 to enable the assessment of the Tertiary Confined Sand Aquifer. Currently, no groundwater information has been presented on salinity or water level trends in the Renmark Group Aquifer.

Bore yields
Groundwater yields of this aquifer range from < 0.5 - 50 l/s, with the majority of yields in the shire varying around 5 - 50 l/s (Mc Auley et al., 1992; Robinson et al., 1992; Mann et al., 1994).

4.3 Dundas Plateau Aquifers
The hydrogeology of the Dundas Plateau section of the West Wimmera Shire comprises the Dergholm Granite and associated meta-sediments as the basement rock. This rock is overlain by Permian till of the Coleraine Glacial Formation. The Sherbrook Group then overlies an alluvial - lacustrine sand and clay formation of the Lower Cretaceous. Tertiary - Quaternary laterite deposits were then deposited; this formation is the uppermost geological unit and dominant aquifer system in the Dundas Plateau.

Groundwater Quality and Quantity
Groundwater quality in this area is not a resource, but rather a hindrance. Salinities of groundwater range from 770 mg/l up to 7700 mg/l with greater quantities of water in the upper salinity levels. The laterite of the area has a very high salt store and changes in the hydrology (post-European settlement) have mobilised the salt (Hill and Day, 1993). Aquifer yields are typically very low with no potential for groundwater extraction in the area.

Recharge and Discharge processes
Laterite deposits on the Dundas Tableland restrict groundwater recharge, and the relatively homogenous nature of the soils means there is little variation in recharge across the area (Hill and Day, 1993). Groundwater discharge of the aquifer is generally restricted to drainage lines and topographically low points and results in areas of land salinisation.

Groundwater trends
Over the last fifteen years of groundwater monitoring, a slight drop in groundwater level across the Dundas Tableland region is apparent (D. Heislers, pers comm). This is in spite of localised land salinisation in topographically low points. Watertable depth on the Dundas Tableland ranges from two to six metres.

Potential Impact of Irrigation on Salinity

A number of areas within the shire are considered to have moderate and high potential groundwater recharge. This includes much of the area to the east of Edenhope and in the southern areas. In these areas, the process is regional with water recharging through the lakes system and areas of deeper sands (generally units Pu13, Pg13 and Ru13). Discharge of saline water occurs in topographically low areas. The regional watertable is the Parilla Sands Aquifer.

In the north of the shire, the dune/swale systems (Big Desert land system) have local recharge and discharge process. In this area, the water recharges through the dune system, picks up salts and discharges in lower, less permeable areas such as swales.

The development of irrigated agriculture and horticulture can, particularly with poor management, increase the risk of a rise in the groundwater table, and the potential for land salinisation either on- or off-site. Irrigation on moderate and high potential recharge areas significantly increases the risk. The development of irrigation on moderate and high recharge areas needs to proceed with due care and should include irrigation systems that are water efficient and allow for safe drainage of excess water.

Chapter 5
SUMMARY OF LAND SYSTEMS, MAP UNITS AND SOILS

5.1 Land resource mapping

The main objective of land resource mapping is to identify uniform areas of land with respect to the characteristics that affect **land use** - where one area is managed differently to another. These uniform areas of land have been identified according to their similar land use suitability for a nominated species (e.g. potatoes, canola, carrots and Blue Gum) and are likely to respond in a similar way to management. By identifying areas of land with a limited range of variability, the resultant base maps provide the basis for land suitability assessments.

The land within the West Wimmera Shire has been divided into land complexes, referred to in this study as **land systems** (Rowan, 1990). Fourteen land systems have been identified and mapped within the shire (refer to section 5.2 General land systems and land elements descriptions). In addition, four land elements (swamps, lakes, lunettes and lake complexes) have also been mapped.

A land system is an area of land that is distinct from the surrounding terrain. Each land system is mapped according to landform, geology, climate, soil and vegetation, and requires specific management practices separate to other land systems.

Each land system has been further divided and mapped into **land units**, based primarily on land pattern. These form the base map units. For instance, the Big Desert-1 land system has been divided into three land units:

Gently undulating plains (Pg1),
Gently undulating plains (closer spaced undulations) (Pu1) and
Gently undulating rises (closer spaced undulations) (Ru1).

Each land unit has attributes that include relief, slope and spacings of undulations. Each of these attributes may affect potential land use (refer to Table 5.1).

(land unit)			(land system)
Gently undulating plains ———	Pg	1	——— Big Desert land system

Figure 5.1 The Big Desert-1 land system showing how the code was developed: the first two letters distinguish the land units and the number separates each land system.

The land systems and land units were delineated using stereoscopic aerial photograph interpretation, satellite imagery and radiometric interpretation. Ground survey was used to ground truth.

Ground survey is a detailed process of identifying appropriate sites, using landform and current land use, to describe the many different soil types that occur throughout the West Wimmera Shire. Common soil types were identified within the land units, and a relationship was determined between position in the landscape and soil type. This forms the basis for land suitability assessments.

To enable land unit and soil type associations, over 200 sites were augered and 35 soil pits were excavated for more detailed analysis. Time restrictions limited the number of sites that could be examined. Therefore, and because of, some generalisations were required when allocating soils to particular land units over the very diverse study area.

The land units have been represented on accompanying maps. These maps are not designed to identify the soils that occur in any part of the mapped units, but to predict the probable occurrence of specific soil associations.

Where possible, soil type associations have been identified either to describe the soil of different land elements, e.g. crest, upper slope and lower slope, or to illustrate the spatial variability of soil types that can occur in the land unit.

Due to the scale of operation, some land units within a land system could not be differentiated on the map. An example is where plains (similar to those in the Southern Cracking Clay Plains -10 land system) occur as small depressions between the rises of the Yellow Gum Plains and Rises -11. The clay plains are too small to be represented on a 1:100 000 scale map where plains.

The scale of mapping for this land suitability study has also meant that there was difficulty in mapping areas where landform was similar and only soil type and vegetation were the major distinguishing factors. An example is differentiating between the Red Gum Plains and Rises -12 land system and the Yellow Gum Plains and Rises -11 land system. In this case the more common soil and vegetation type has defined the land system. More detailed on-ground surveys to better delineate these land system boundaries will be required if agricultural development is to occur.

5.2 General land systems and land elements descriptions

The West Wimmera Shire has a range of environments from north to south. There are also a wide range of landscapes and soil types. Fourteen land systems have been defined, with further division into land units using the pattern of the land (refer to Table 1). (Included in Table 1 are four land elements: 14. Lunettes, 15. Intermittent Swamps, 16. Permanent Waterbodies, 17. Swamp and Lake Complex).

Land systems

1. Big Desert

Defines the sandy soils south of the Big Desert Wilderness Park.

2. Big Desert Transition

An area of sandy low rises and swales south of land system 1 (see above), used to show the southerly transition away from the Big Desert land system and towards land system 5 (Grey and Red Plains and Rises).

3. Stranded Beach Ridges

Incorporates the low hills and rises that are believed to be stranded beach ridges from the retreat of the sea. Along with the landscape being of higher relief, the ridges are significant because the Parilla sand is generally close to the surface. The undulating plains unit of this system, although of lower relief, still has evidence of the Parilla sand close to the surface with some superficial sand deposits above the Parilla sand.

4. Northern Cracking Clay Plains

Situated in the north of the shire, this land system defines the depressions, or swales, that lie between the ridges and are commonly aligned NNW-SSE. It has a similar landscape pattern and similar soils to land system 10 (Southern Cracking Clay Plains), although it has been spatially separated by the Little Desert.

5. Grey and Red Plains and Rises

A complex of *sodosols* (see definition Chapter 5.4) on the crests of rises and *vertosols* (see definition Chapter 5.4) on the slopes. A significant characteristic of this land system is the range of soil colours on the rises. The crests and upper slopes have red or brown soils and the lower slopes have a more grey hue.

6. Limestone Rises

This land system, or 'complex', indicates broadly where terra rossa type soils occur. Terra rossa soils are shallow, porous and well drained soils formed on limestone or highly calcareous parent materials. Note: This unit also incorporates other soils (mostly *sodosols* and *vertosols*), as the occurrence of terra rossa type soils is very small in area, and is thus mapped as part of a 'complex'.

7. Self-mulching Clay Plains

Cracking clay soils (*vertosols)* with a *self-mulching* (see definition Chapter 5.4) surface predominate in the area to the south of Serviceton.

8. Little Desert Transition

The area of land immediately north of the sandier land system 9 (Little Desert). The landscape is characterised by low hummocks of sand rises alternating with clayier swales or depressions.

9. Little Desert

A large proportion of this land system makes up part of the Little Desert National Park. The remainder of the unit has been cleared for agriculture, and is characterised by sand dunes, low sand sheets and clay flats or depressions.

10. Southern Cracking Clay Plains

Comprising cracking clay soils (*vertosols)*, south of the Little Desert, and either formed as narrow swales between sandy rises, or as larger plains around Neuarpurr. This unit is very similar to land system 4 (Northern Cracking Clay Plains) although it has been spatially separated by the Little Desert.

11. Yellow Gum Plains and Rises

The main tree species found of this land system is Yellow Gum. This land system consists of *sodosols* although they have distinctive characteristics that are better defined by the Great Soil Group terminology of *solodised solonetz* (see definition Chapter 5.4).

12. Red Gum Plains and Rises

The main tree species found on this land system is Red Gum. This land system consists of *sodosols,* commonly with the occurrence of ferruginous nodules ('buckshot') above the clay.

13. Sand Plains and Rises

Lying south of the Little Desert this land system consists of areas with windblown sand deposits that are deeper than on adjacent land systems (e.g. 11 and 12). This unit is distinct from the adjacent units (mostly Red Gum Plains and Rises-12 and Yellow Gum Plains and Rises-11) because of the distinct change in vegetation (Brown Stringybark, Banksia, Blackboys and heathland species).

18. Dissected Tableland

Comprises the dissected tableland in the south of the shire that encompasses a range of geologies (Tertiary and Ordovician sediments, granite, basalt and limestone) that occur in close proximity. The main feature that defines this unit is the landscape of dissected hills and rises. This unit only occurs on the southern boundary of the shire and is caused by the Glenelg River and its tributaries dissecting the ferruginised clay plain of the Dundas Tablelands.

Land elements

14. Lunette

This unit delineates the wind-blown crescent shaped formations, called lunettes, formed on the eastern side of lakes and some swamps.

15 Intermittent Swamps

Swamps that are partially or fully dry during drier periods.

16. Permanent Waterbodies

Lakes that remain full of water throughout the year.

17. Swamp and Lake Complex

Where chains of lakes and swamps occur, particularly south of Edenhope, they have been mapped as a complex unit, and include intermittent swamps, permanent lakes and associated lunettes and clay plains.

5.3 Definition of map units

Each land system has been divided into land units based on land pattern such as relief, modal slope or spacing of undulations. The land units are delineated on the map. There are also four land elements defined on the map. See Table 5.1 for the name of each land system and its respective land units and map codes. Each land element has been similarly listed.

Table 5.1 Land system and land element names and the land units or land elements within each land system and definitions of the map unit code that is represented on the accompanying maps

Land system	Land unit description	Map unit
Big Desert-1	Gently undulating plain Gently undulating plain (closer spaced undulations) Gently undulating rises (closer spaced undulations)	Pg1 Pu1 Ru1
Big Desert Transition-2	Gently undulating plain	Pg2
Stranded Beach Ridges-3	Undulating low hills Undulating plain Undulating rises	Lu3 Pu3 Ru3
Northern Cracking Clay Plains-4	Gently undulating plain Level plain	Pg4 Pl4
Grey and Red Plains and Rises-5	Gently undulating plain Gently undulating plain (closer spaced undulations) Gently undulating rises Gently undulating rises (closer spaced undulations)	Pg5 Pu5 Rg5 Ru5
Limestone Rises-6	Gently undulating plain Undulating plain	Pg6 Pu6

Self-mulching Clay Plains-7	Gently undulating plain	Pg7
Little Desert Transition-8	Gently undulating plain Undulating rises	Pg8 Ru8
Little Desert-9	Gently undulating plain Gently undulating plain (closer spaced undulations) Gently undulating rises (closer spaced undulations)	Pg9 Pu9 Ru9
Southern Cracking Clay Plains-10	Gently undulating plain	Pg10
Yellow Gum Plains and Rises-11	Gently undulating plain Gently undulating plain (closer spaced undulations) Gently undulating rises (closer spaced undulations)	Pg11 Pu11 Ru11
Red Gum Plains and Rises-12	Gently undulating plain Gently undulating plain (closer spaced undulations)	Pg12 Pu12
Sand Plains and Rises-13	Gently undulating plain Gently undulating plain (closer spaced undulations) Undulating rises Undulating low hills	Pg13 Pu13 Ru13 Lu13
Dissected Tableland-18	Dissected hills Dissected low hills Undulating low hills Dissected rises Undulating rises	Hd18 Ld18 Lu18 Rd18 Ru18
Land element	**Land element description**	**Map unit**
Lunette - 14	Lunette	Nu14
Intermittent Swamps-15	Intermittent swamp	Wg15
Pemanent Waterbodies-16	Permanent water bodies	Wg16
Swamp and Lake Complex-17	Intermittent swamps, permanent waterbodies, lunettes, clay depressions and clay plains	Wg17

5.4 General soil descriptions

The major soils found in the survey were sodosols and vertosols. Although there are a range of soil types throughout the shire there is a commonalty in the soil types on many of the land systems: the presence of sand over clay. The sand in many cases is hydrophobic (i.e. repels water) and the clay subsoil is commonly *sodic*. These soil types are referred to as *sodosols* using the Australian Soil Classification (Isbell, 1996).

Sodosols are also known as ‘duplex soils’ (Northcote, 1979) because of their strong textural contrast between the topsoil (often sand or loamy sand) and the subsoil (clay). The subsoils are not strongly acid but are *sodic* (i.e. soils with high concentrations of exchangeable sodium on the clay surfaces.) The high exchangeable sodium makes the clay subsoil strongly *dispersive* (i.e. individual clay particles separate in water.) Dispersion destroys the structure of the soil and, as a result, sodic soils are often hardsetting, prone to water logging and hostile to root growth.

In this study, most of the sodosols have a bleached (pale colour) sandy subsurface horizon (A2) and a mottled (splashes of bright colours) clay subsoil. This is often an indication of impeded internal drainage. There are differences in the depth of sand, the structure of the clay and the presence of ferruginised iron nodules in these sodosols. Two major types of sodosols occuring in the shire have been referred to by more descriptive terms - *ferric sodosols* and *solodised solonetz*.

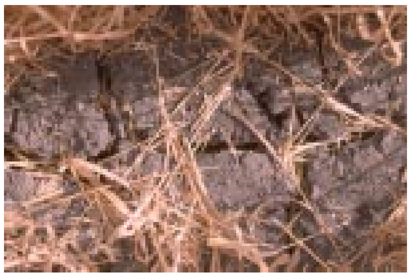
Ferric sodosols have a layer of ferruginised (iron) nodules (often called ‘buckshot’) above the clay. Ferric sodosols are most prominant in the Red Gum Plains and Rises -12 land system, although they can also occur on the Sand Plains and Rises -13 land system.

Solodised solonetz: is a Great Soil Group (Stace et al. 1968) term. Solodised solonetz are sodosols because of the strong textural contrast between the topsoil and the sodic subsoil. The significant characteristic of solodised solonetz is a very distinctive and conspicuously bleached, slightly rounded capping over large hardsetting columns, or prisms, of clay. The cracks of the prisms are obvious when the topsoil is cleared away as shown in the adjacent photograph.

Solodised solonetz are most prominant in the Yellow Gum Plains and Rises-11 land system, although they also occur in the Big Desert -1, Big Desert Transition -2 and Little Desert Transition - 8 land systems.

Another major soil type in the shire is the *vertosols* (Isbell, 1996) that commonly occur on the lower lying areas.

Vertosols, often called ‘uniform cracking clay soils’, have a clay texture throughout the profile and display strong cracking when dry (see adjacent photo). The cracks are caused by the high shrink-swell capacity of the soil due to the high clay percentage and the type of clay present. The cracking characteristic of the soils often leads to *gilgai micro-relief* (also known as ‘crabholes’)



Vertosols occur on the Northern Cracking Clay Plains-4, Southern Cracking Clay Plains-10, Self-mulching Clay Plains-7 and the slopes of the Grey and Red Plains and Rises-5 land systems.

Some vertosols, in particular the soils of the Self-mulching Clay Plains -7 land system, have a self-mulching surface and are known as *self-mulching vertosols*.

Self-mulching vertosols: a clay texture throughout the profile and displaying strong cracking when dry. This soil type also has a surface layer that forms a shallow mulch of well aggregated soil when dry.

Gilgai micro-relief*:* all vertosols and some of the sodosols in the shire have *gilgai micro-relif* occuring on the land surface. Gilgai are common in areas with vertosol (uniform cracking clay) soils, and result in an irregular land surface with alternating mounds and depressions. It is commonly referred to as 'crab hole' country. Gilgai micro-relief is formed by clay horizons that alternately shrink when dry and swell when wet (known as having vertic properties). This process forces 'blocks' of subsoil to gradually move upwards to form mounds. The soil on the mounds has properties that is more like the subsoil of a grey vertosol: lighter colour, more alkaline, presence of carbonate, higher salinity. Continuous cultivation of paddocks with gilgai has resulted in the smoothing out of many of these formations. However, the process that formed the gilgai is still operating and is evident by the displacement of fence posts. When the land is left undisturbed for a number of wetting and drying seasons gilgai will re-form. Crop and pasture growth is likely to be uneven across a paddock due to two main factors: the variation in soil across each mound and the poor drainage conditions in the depressions (crab holes).

Plate 1. Landscape showing gilgai mounds and depressions.

Plate 2. Gilgai micro-relief on the Northern Cracking Clay Plains -4 land system (Pg4). Note the greener pea crop in depressions and poor crop on saline mounds.

Soil pH trends: Many of the soils in the shire have high levels of calcium carbonate in the subsoil, that increases pH and provides an increasingly alkaline trend down the profile.

In the southern area of the shire the soils often become more acidic in the subsurface (A2) or in the top of the subsoil (B21) before the typical alkaline trend with depth takes over. This more acidic layer can become the most important soil characteristic of these soils. The land system where these pH trends are most prominant is the Dissected Tablelands-18, although acid subsoils can also occur in some soils related to the Sand Plains and Rises-13, Red Gum Plains and Rises-12, and Yellow Gum Plains and Rises-13. The probability of acid subsoils increases the further south of the Shire the soils occur.

Deep Sands: Other minor soils in the shire are deep sands that occur mainly on the dunes associated with the Big and Little Desert land systems (land systems 1, 2, 8 and 9). Some of the dunes have very little clay development and are designated.

Plate 3. The grey vertosol (left) is similar to that found on depressions, and the brown vertosol (right) typically occurs on gilgai mounds.