2005

**Tonebridge-Frankland area land resources survey**

Angela Stuart-Street

National Landcare Program (Australia)

Natural Heritage Trust (Australia)

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TONEBRIDGE-FRANKLAND AREA
LAND RESOURCES SURVEY

by Angela Stuart-Street

Land Resources Series No. 19

Department of Agriculture, Western Australia
3 Baron-Hay Court
South Perth 6151

Funded by the National Landcare Program and Natural Heritage Trust
Disclaimer

This Survey report is designed for use at the publication scale (1:100,000). The scale influences:
- how homogeneous the map unit is,
- how accurate the lines are, and
- how accurate the descriptions and attributions are.

Descriptions of map units apply to the whole survey and to any occurrences in adjacent surveys. Individual map units may differ considerably from this description in terms of the proportion of different soils and landforms that occur within them. Thus, the map provides a guide to what soils may occur at a particular point or in selected area, not a definitive statement.

Tone bridge over the Tone River in the centre of the survey area, fringed by flooded gums (Eucalyptus rudis).

Cover Photo:
The Frankland Hills system, west of Frankland, displays a diversity of agricultural land uses from viticulture and olives to grazing, cropping and agroforestry."
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Summary

This report presents the results from soil and landform mapping at a scale of 1:100,000 in the Tonebridge-Frankland area of Western Australia. One map representing the Tonebridge (2229) and Frankland (2329) map sheet areas, covering approximately 511,000 hectares accompanies the report on a CD-ROM.

The Tonebridge-Frankland survey area covers major parts of the Warren-Tone and Frankland-Gordon River catchments. It also covers the upper catchments of the Kent and Deep Rivers, a small part of the Blackwood River catchment in the north western corner, as well as the Lake Muir-Unicup sub-catchments. The Tonebridge-Frankland survey falls within the Manjimup, Katanning and Albany advisory districts for the Department of Agriculture, Western Australia.

The land resource information has been collected to help improve the decisions made by planners, researchers and land managers. The information can be used from regional scale, to catchment scale to farm level. By improving knowledge of the land resources, more sustainable land uses can be developed within the Tonebridge-Frankland region.

Sixteen soil-landscape systems were identified during the survey. These systems were further divided into subsystems. The accompanying CD-ROM provides details of the main soils, landforms, geology, land use and native vegetation for each system. Also within each subsystem, the proportion of unmapped units (land units) is also indicated.

The report includes a summary of the main soils recognised within the area. The major land degradation hazards identified during the survey are also outlined. This assessment is designed to give a broad overview of the limitations of the soils in the area. For specific land capability assessment it is recommended that the Department of Agriculture’s dynamic Map Unit Database be consulted to get the most current assessments of land qualities and land capabilities for specific land uses.

Information on land use history, geology and physiography, climate, native vegetation and previous soil surveys are included in the report. These sections provide additional background material about the land resources within the Tonebridge-Frankland survey.
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Introduction

Prior to the Tonebridge-Frankland survey, very little information on the landforms and soils of the area was available, apart from a small-scale map (1:2,000,000), the *Atlas of Australian Soils* (Northcote *et al.* 1967), and a few small detailed maps. The latter included some detailed soils mapping prepared in the late 1940s by soil scientists from the Council for Scientific and Industrial Research (CSIR) on properties in the area prior to closer settlement. Consequently, the lack of integrated soil information for the region has hindered communication about the soils and their management.

The objectives of the Tonebridge-Frankland survey were to:

- provide a mapped inventory of soils and landforms at a regional scale (1:100,000) for the Tonebridge (2229) and Frankland (2329) map sheets;
- collate and disseminate information on the nature and extent of soils and landscapes in the survey area for research and land management purposes; and
- during the period of the survey, to provide soil-landscape information and to assist in soil mapping workshops for landcare groups working on farm and catchment planning, thereby providing information to farmers on the variability and properties of soils and the different management strategies for different soil types.

The survey was undertaken by the Department of Agriculture and was funded by the Commonwealth and Western Australian Governments under the National Soil Conservation and National Landcare Programs. It was part of a program to map the land resources of the agricultural regions of Western Australia.

At regional level, the information in this report can be used for land use and land management planning, and in the development of conservation policies and strategies to overcome land degradation. It can also be used for planning and targeting research funding and to help communicate research results. At the farm scale this information should be considered indicative only, but it does provide a framework for detailed scale assessment.
How to use this report and CD-ROM

The report and accompanying CD-ROM provide the summarised collation of information about the soils and land resources of the Tonebridge-Frankland region. The report provides an overview of the past and present uses of land in the area, and the geology and native vegetation associations to develop an appreciation of the components of the landscape and its developmental characteristics.

The soil-landscape map and the detailed survey results are presented on the accompanying interactive CD-ROM using Web-browser software. A hard copy of the soil-landscape map, or a portion thereof, can be purchased from the Department of Agriculture. It is also possible to purchase part of this map together with a portion of an adjoining survey.

The CD-ROM is a complete presentation of the survey results plus several supporting documents and general information of Land Resource Assessment in Western Australia. It is designed for better access to information and to allow efficient creation of new editions as new information and better interpretations are made.

The map and associated files on the CD-ROM have three main functions:
- to describe and represent spatially areas with similar soil and landforms;
- to identify soils and associated soil properties at a point or in area of interest; and
- to show the general distribution of soils, soil properties or land qualities.

Descriptions

A series of auto-generated descriptions comprise the core of the CD-ROM. These are generated from various areas. There are a number of types of descriptions:

1. Soil-landscape zone
   - a map of its occurrence in the current survey;
   - descriptions of the unit; and
   - an outline of the systems within the zone. These have links to the system descriptions.

2. Soil-landscape systems
   - a map of its occurrence in the current survey;
   - descriptions of the system under the headings: location, landform, geology, soils and vegetation;
   - an outline of the map units which comprise the system within the survey area (with links to the subsystem descriptions);
   - a schematic diagram of the relation of subsystems and phases within the system; and
   - a summary of the WA Soil Groups present in the system (with links to the Soil Group descriptions).

3. Mapped Units (usually subsystems and phases)
   - a description of the map unit under the headings: landform, geology, soils, and vegetation;
• a table presenting the expected proportion of unmapped land units in the subsystem. Each land unit is a combination of a WA Soil Group, the soil group qualifier and landscape position. There are usually several land units present, each occupying different proportions of the map unit. The most common named soil (soil series) for each land unit may be included under the heading Main Soil. Each land unit has links to WA Soil Groups, land qualities and Main Soils.

4. Land Qualities
• tabulation of the attributed land quality values for the current land unit with links to the definition of the land qualities.

5. Main Soils
• description of the main soil with links to the description of soil profiles.

6. WA Soil Groups
• description of the current WA Soil Group with links to a distribution map and photo.

7. Soil Points
• description of the location of the soil point, morphological description of the layers observed and a tabulation of any laboratory data.

The home page on the CD-ROM is a menu that provides access to various aspects including report chapters, mapping and of specific map units, main soils or soil point observations. Most of these documents have links to different portions of the results. If you want a specific map unit or soil, use the menu to open the descriptions. If you want to view the mapping or a particular portion of it, click on the “Interactive Maps”.

Mapping

The presentation of the mapping is designed to show various map themes (left-hand side menu, e.g. soil-landscape systems), each with its own suite of legend items, e.g. towns and roads (right-hand side menu). The legend items can be turned on or off individually. The maps are interactive, as moving the cursor over the map window will demonstrate. The active map unit will be highlighted and a brief yellow label (known as a tool-tip) will appear. By clicking on the map window, a report of either the active map unit or soil point is generated.

Soil-landscape maps are presented as three levels of detail: zones, systems and mapped units. The latter is typically a combination of subsystems and phases. You may choose the particular level or start with zones and zoom in. This will automatically switch to the more detailed mapping as the scale rules are invoked.

You can view the whole map and then zoom and pan into an area of interest. Alternately, you can use the Find tool that, after selection, focuses you on the selected locality or road name.

There are two types of interpretive maps, one showing the distribution of the main WA Soil Groups and one showing the distribution of the main land degradation issues. Both are based on the subsystems mapping and can only be viewed at that scale.
Location

The Tonebridge-Frankland survey corresponds to two 1:100,000 map sheets from the national topographic map series: Sheet 1 (Tonebridge - 2229) covers the western half and Sheet 2 (Frankland - 2329) covers the eastern half of the survey.

The survey covers approximately 511,000 hectares in the Great Southern and South West regions in the south-west of Western Australia (Figure 1). Most falls within the Warren-Tone and Frankland-Gordon River catchment areas. It also covers the upper catchment of the Kent River, the northern headwaters of the Deep River and part of the Blackwood River catchment in the north-western corner (Figure 2). The majority of the mostly internally drained Lake Muir-Unicup sub-catchment with its numerous permanent and ephemeral wetlands is also within the survey area.

The only town within the area is Frankland. Rocky Gully, Tenterden and Cranbrook are located close to the survey boundaries. The Albany Highway passes through the north-east of the area, and Muirs Highway passes through the south-west. It is well serviced by secondary and minor roads.

Six local government areas are represented: the south-eastern portion of Boyup Brook Shire; the southern part of the Kojonup Shire; the western half of Cranbrook Shire; the western tip of the Tambellup Shire; the north-eastern corner of Manjimup Shire; and small areas in Plantagenet and Bridgetown-Greenbushes Shires.

Figure 1. Location of the survey in relation to the rest of Western Australia
History of land use

The first inhabitants of the land in the Tonebridge-Frankland area were the Aborigines of the Kaneang tribe, whose territory extended as far east as Tenterden (Pope 1994). Their legacy continues today with many of the place names in the area retaining their Aboriginal form.

John Septimus Roe passed through the eastern portion of the survey area on his return journey from Albany during the Great Southern Expedition of 1835. He came to a waterway named Pakeerup, made up of a series of fresh pools surrounded by areas of broad grassy plains with few trees. He judged it to be ideal for grazing and named it the Gordon River in honour of the Earl of Aberdeen (Laurie 1994).

Dr Thomas Braidwood explored the area around Frankland in 1829. He traversed the land around the headwaters of the Kent River and further west to discover a larger stream, which he named the Macqoid. This eventually became known as the Frankland River. In 1846, surveyor Augustus Charles Gregory traced the Gordon River down to its junction with the Frankland River, and then further on to Normalup.

Europeans first explored the south-western portion of the Tonebridge-Frankland area in 1852. A group that included Robert Muir discovered and named Lake Muir. They also explored the vicinity of the Perup River. In 1856, the Muirs moved their sheep flocks from the Hay River up to the Frankland area, but finding the land very poor, moved west to the region around Lake Muir and beyond (Laurie 1994).

Early settlers had arrived by 1857 and concentrated on wool production. Other newcomers progressively cleared more land and grew oats and barley. They also kept cattle for meat and milk, as well as pigs. The area they settled was known as Gordon until 1900 when it was renamed Frankland River, and was later shortened to Frankland in 1935 (Hilder 1978).

The early timber industry was prominent in the west. The Bunning brothers secured timber rights in the Perup area and set up a few large mills which supported small towns such as Tone River (also known as Strachan) and numerous smaller mills. Albion, Chowerup and Cabbage Tree Mills are examples of these. In the long-term, however, the timber industry in this area was not as successful as it was in the higher rainfall areas to the west. Many timber workers remained and took up smaller properties for farms (McConnell 1983).

By the turn of the century, agricultural enterprises largely consisted of sheep grazing for wool production, with all the wool being shipped to London. The establishment of crops in the region was hindered due to difficulties in clearing the land using the methods of the day. Harvesting activities such as mallet bark stripping and carting and collection of kangaroo, tamar and possum skins were common.

The gold rush provided land holders with new market opportunities. The growth in population increased the demand for food, and access to markets was made easier by the opening of the Great Southern Railway in 1889. Fruit growing was established in the area, with large orchards at Yeriminup and Boyacup. These, however, would fail in the long-term.

By the early 1900s there were a few large landholders who leased thousands of acres plus many smaller land holders who worked as shepherds, boundary riders, and sandalwood
cutters. Difficulties encountered included the loss of sheep to poison bush plants (e.g. *Gastrolobium* spp.) and dingoes. At about this time, the Land Selection Act (1898) encouraged leaseholders to purchase land, and settle in Western Australia. This meant the end of unhindered grazing lease holdings, and the beginning of fenced boundaries and paddocks. Prior to this, there was a vast cattle run in bushland between Tunney and Rocky Gully (Laurie 1994). To gain some extra income, early settlers in the Tone River area and north to Balgarup had also been engaged in breeding, catching and breaking wild horses for sale (Bignell 1971).

There was still a lot of uncleared land across the region until the development of the War Service Land Settlement properties scheme in 1949. Ringbarking, burning and the introduction of the bulldozer removed much of the virgin bush, and agricultural land use became more intensive.

When the area was recommended as being suitable for grape growing, a five-acre trial of grapevines was planted in 1967 to the south-west of Frankland. It was found to be successful and numerous vineyards have since been established.

Increasing concern over the gradual salination of waterways in the area due to agricultural clearing led to an extension of the existing Country Areas Water Supply Act in 1978 (Public Works Department 1980). This introduced clearing control legislation to protect the Warren-Tone, Kent and other southern rivers. The Warren-Tone was seen as particularly important as it is the largest single source of potable water in the South West region. The Kent was regarded as significant for the Albany region.

Three areas within the survey are currently the focus of assessment and planning as part of the State Salinity Strategy (State Salinity Council 2000). These are Recovery Catchments for natural diversity protection (Muir-Unicup) and water resource recovery (Warren-Tone and Kent catchments).

*Annual winter-growing pastures, such as here in the Farrar System, are the dominant land use in the survey area.*
Current land use

The eastern two-thirds of the Tonebridge-Frankland survey area is largely utilised for dryland agricultural production. Annual winter growing pastures dominate, but cropping is becoming more widespread. Cereals (wheat, barley and oats) are the most important crops with significant areas also being sown to canola. Wool and sheep-meat production is widespread in the region and beef cattle enterprises are also common. Sheep numbers declined during the 1990s. Since about 1998, however, there has been a significant turn around in stock numbers with the increase continuing.

With the rapid adoption of viticulture in the south of the survey area, the Great Southern region is now a major centre in the Western Australian wine industry. Olive growing is an emerging industry. Small areas of annual horticulture have also been established. All horticulture is irrigated using on-farm water supplies.

Hardwood and softwood timber plantations are common in the south and west of the area. State Forest that is managed for selective logging of mainly jarrah (Eucalyptus marginata) sawlogs dominates the western third. Nature conservation is a significant land use here also, including the Perup Forest and the Lake Muir/Unicup complex of Nature Reserves (Department of Conservation and Land Management 1998).

This young blue gum (Eucalyptus globulus) plantation in the Frankland Hills System is typical of many across the south of the survey area.
Climate

The Tonebridge-Frankland area has a Mediterranean climate with hot, dry summers and mild, wet winters. Mean average annual rainfall varies from about 820 mm in the south-west to just over 500 mm in the east. Mean daily minimum and maximum temperatures range from 5 to 16°C in winter and from 12 to 29°C in summer. A summary of climatic data is presented from the Australian Rainman program (Clewett et al. 1994) and Silo Data Drill database (Queensland Department of Natural Resources 2002).

Rainfall

The highest rainfall is experienced in the south-west with an average of 826 mm recorded at Lake Muir. There is a decrease in rainfall toward both the north-eastern (536 mm) and eastern (504 mm) boundaries (Figure 2). This reflects the winter cold fronts from the Indian and Southern Oceans bringing more rain into the western and southern parts of the survey area.

Figure 2. Average annual rainfall and catchments in the survey area, with recording station locations
Rainfall is concentrated in the late autumn and winter months with more than half the average annual rain falling from May to August. More than 70% of annual rainfall occurs between May and October (see Tables 1 and 2 for rainfall statistics). The amount of rain falling in winter and spring is more consistent (on a year to year basis) than that falling in summer and early autumn. This is exemplified by the “difference %” (100*(mean-median)/mean), which is about 50% in summer and less than 10% in winter. This seasonal variation indicates relatively uniform, widespread winter rain as occurs in frontal systems and irregular, patchy summer rain occurring in thunderstorms (Table 2).

Table 1. Mean and median monthly and annual rainfall for five recording stations (Clewett et al.1994 and Queensland Dept. of Natural Resources 2002).

<table>
<thead>
<tr>
<th>Location</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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<tbody>
<tr>
<td>Lake Muir</td>
<td>mean</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>51</td>
<td>107</td>
<td>132</td>
<td>147</td>
<td>120</td>
<td>86</td>
<td>68</td>
<td>32</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>7</td>
<td>7</td>
<td>22</td>
<td>44</td>
<td>98</td>
<td>118</td>
<td>140</td>
<td>112</td>
<td>78</td>
<td>66</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>Westbourne</td>
<td>mean</td>
<td>15</td>
<td>18</td>
<td>25</td>
<td>43</td>
<td>92</td>
<td>116</td>
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<td>7</td>
<td>17</td>
<td>35</td>
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<td>92</td>
<td>69</td>
<td>50</td>
<td>26</td>
<td>13</td>
</tr>
<tr>
<td>Wonnenup</td>
<td>mean</td>
<td>19</td>
<td>18</td>
<td>21</td>
<td>35</td>
<td>77</td>
<td>88</td>
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<td>72</td>
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<td>89</td>
<td>65</td>
<td>43</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>Teresa Dale</td>
<td>mean</td>
<td>16</td>
<td>16</td>
<td>20</td>
<td>38</td>
<td>68</td>
<td>87</td>
<td>86</td>
<td>71</td>
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<td></td>
<td>median</td>
<td>5</td>
<td>5</td>
<td>11</td>
<td>28</td>
<td>71</td>
<td>87</td>
<td>84</td>
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<td>73</td>
<td>62</td>
<td>51</td>
<td>40</td>
<td>20</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2. Selected rainfall statistics for representative locations (Clewett et al.1994 and Queensland Dept. of Natural Resources 2002).

<table>
<thead>
<tr>
<th>Location</th>
<th>Minimum (mm)</th>
<th>Mean (mm)</th>
<th>Maximum (mm)</th>
<th>Mean Rain days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Muir</td>
<td>482</td>
<td>826</td>
<td>1,235</td>
<td>112</td>
</tr>
<tr>
<td>Westbourne</td>
<td>403</td>
<td>698</td>
<td>1,130</td>
<td>114</td>
</tr>
<tr>
<td>Wonnenup</td>
<td>282</td>
<td>608</td>
<td>747</td>
<td>155</td>
</tr>
<tr>
<td>Teresa Dale</td>
<td>165</td>
<td>536</td>
<td>852</td>
<td>97</td>
</tr>
<tr>
<td>Cranbrook Post Office</td>
<td>300</td>
<td>504</td>
<td>744</td>
<td>127</td>
</tr>
</tbody>
</table>

The Indian Ocean Climate Initiative (IOCI) has recently released a summary of climatic variability in south-western Australia. This summary shows that winter rainfall has decreased substantially since the mid-20th century. They suggest that the climate of the south-west will continue to exhibit wet and dry periods over the 21st century, with a probability of decreased winter rainfall and warming temperatures (IOCI 2002). Changes in climate are likely to have major land use implications. Reduced winter rainfall may result in lower crop and pasture yields. The reduction in run-off has serious implications for water supplies. Erosion and flooding in the summer may increase as summer thunderstorms become more common (Tille et al.in prep.).
Temperature

The average minimum and maximum temperatures for each month for five locations are presented in Table 3. This also includes the highest and lowest temperatures recorded. Temperatures vary little between locations but there is a general gradient from south to north across the area. Inland areas to the north east of the survey (Teresa Dale) are marginally warmer in summer and cooler in winter than the south west corner. This, in part, reflects the influence of the sea breeze (the ‘Albany Doctor’) from the Southern Ocean, plus continental heating and cooling of the interior.

Table 3. Selected temperature data for representative locations (Clewett et al. 1994 and Queensland Dept. of Natural Resources 2002).

<table>
<thead>
<tr>
<th>Location</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td>Westbourne</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Min (°C)</td>
<td>13.2</td>
<td>13.5</td>
<td>12.4</td>
<td>10.3</td>
<td>8.1</td>
<td>6.7</td>
<td>5.7</td>
<td>5.7</td>
<td>6.6</td>
<td>7.6</td>
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</table>

Summer temperatures range from a mean minimum of about 12°C to a mean maximum of 29°C. Temperatures over 40°C have been recorded from November to March. Winter temperatures (June to August) range from a mean minimum of 5°C to a mean maximum of 16°C. Temperatures below zero have been recorded from May to October. The risk of frost is an important consideration when growing crops on low-lying valley flats and alluvial plains within the area.
Evaporation

Estimates of Class A pan evaporation for the survey area are presented in Table 4. The evaporation increases across the area from west (1,331 mm Lake Muir) to east (1,438 mm Wonnenup). The monthly estimates show evaporation is highest in December and January and lowest in June and July.

Table 4. Monthly and annual estimates of Class A pan evaporation and evaporation losses from dams in mm (Queensland Dept. of Natural Resources 2002).

<table>
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<th>Location</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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</table>

*Cropping is becoming more prominent across the area like this canola west of Frankland*
Crop variety testing areas

The crop variety testing (CVT) areas for the whole of the south of Western Australia are based on the length of the growing season and annual average rainfall. The length of growing season is divided into five zones from north to south and the annual average rainfall is divided into rainfall regions, from high to low. These zones have recently been amalgamated into Agzones, which have been developed through the statistical analysis of crop performance (Littlewood 2003). The CVT/Agzone areas are used in the crop sowing guides produced annually by the Department of Agriculture for cereals, oilseeds and legume crops.

The Tonebridge-Frankland survey is predominately in one CVT area, H5W, which corresponds to the South growing season zone within the high (450-750 mm) rainfall region (Figure 3). It lies within Agzone 3 - South West. The small section of the survey in the south-west corner covered by the VH5 CVT is an area where broadacre cropping is not a widespread land use.

![Diagram of crop variety testing areas](image)

<table>
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<tr>
<th>Zone</th>
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<th>Rainfall range (mm)</th>
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<td>H5W</td>
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<tr>
<td>VH5</td>
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Figure 3. Crop variety recommendation areas in the survey area.
Geology

The regional geology for the area has been described on the Pemberton-Irwin Inlet 1:250,000 map sheet by Wilde and Walker (1984) and on the Mt Barker-Albany 1:250,000 map sheet by Muhling and Brakel (1985). Myers (1990a,b) provided an overview of the area. Smith (1997) summarises the geology and describes the hydrogeology for the eastern region and De Silva (2000) has mapped the hydrogeology to the west.

The survey lies across the boundary of the Archaean Yilgarn Craton to the north and the Proterozoic Albany Fraser Orogen to the south (Figure 4). These structures are characterised by crystalline rocks, predominantly granite and gneiss, and are often deeply weathered. Sediments overlie a large proportion of the basement rocks across the survey and extensive laterisation has occurred. Toward the eastern boundary is the western most expression of the Proterozoic Stirling Range, Geekabee Hill (400 m).

The geological structure of the northern half of the survey is influenced by the margin of the Yilgarn Craton known as the Western Gneiss Terrane (Myers 1990b) where intrusions of granite are widespread.

The Albany Fraser Orogen to the south is characterised by high-grade gneisses with granitoid intrusions. The Biranup Complex (Myers 1990a), which is a belt of complex of high-grade gneisses and layered granitoid intrusions, lies between the Albany Fraser Orogen and the Yilgarn Craton.

The uplifted metasediments of the Stirling Range formation are part of the northern foreland of the Albany Fraser Orogen. Typical of the western portion of the range it is less prominent and more rounded than the range is in the east. The range displays three distinct units – lower and upper units of quartzite, and a middle unit of quartzite, slate and phyllite. It appears to be fault bounded and has youthful relief compared to the surrounding Yilgarn Craton and Albany Fraser Orogen.

Cainozoic sedimentary deposits over the crystalline rocks are widespread across the Tonebridge-Frankland area. The early deposits are associated with the major Eocene marine transgression. Subsequent deposits extend across the main physiographic provinces. Some of these are associated with WNW-trending palaeodrainages. In the south of the survey, sediments of the Plantagenet Group (Werrilup Formation and Pallinup Siltstone) partly overlie the crystalline rock (Smith et al.2004).

The most extensive Cainozoic material across the area, however, is laterite that forms an undulating capping over the rocks of the Yilgarn Craton and the northern part of the Albany Fraser Orogen. The laterite varies from massive and cemented, with either a pisolitic or vesicular texture to loose, un cemented pisolites.
Figure 4. Major geological structural units within the survey area

The appearance of the lateritic or deeply weathered profile is variable from west to east across the survey. In the west, it is largely present as an intact, deeply weathered profile sequence typical of the Darling Plateau, which includes sandy or gravelly topsoil, duricrust and mottled clays over bedrock. This sequence may also include layers of pallid zone clay and partially weathered rock or saprolite. Further to the east, the lateritic plateau has been incised, and the full profile may appear only as isolated remnants or breakaways. Many of these lateritic profile remnants are very eroded with some horizons no longer present. Sometimes only the bedrock is left. This has resulted in the products of the eroded lateritic profile becoming the source of new soil development in the landscape through the redistribution of colluvium and alluvium.

Many hypotheses have been proposed regarding laterite formation and these are summarised in several texts (e.g. McArthur, 1991; Tille et al. 1998; Percy 2000 and Tille et al.2001). Pate et al. (2001) recently presented a new hypothesis suggesting that lateritic materials represent a by-product of symbiotic bacteria feeding on exudates from specialised (cluster) roots of plants such as Proteaceae. They argue that the process has been operating over geological time scales and is currently active.
Physiography

The survey falls mainly within a physiographic region known as the Ravensthorpe Ramp (Cope 1975). This is the name given to the land that slopes gradually southward to the coast. Adjoining it to the north is the physiographic region called the Darling Plateau. This is an ancient erosional surface that was originally formed during the Proterozoic period and extensively laterised during the Tertiary period. The divisional line between the Darling Plateau and the Ravensthorpe Ramp is known as the Jarrahwood Axis (Cope 1975). This ‘hingeline’ corresponds to the boundary that separates the northward directed and southward directed drainages. A small area in the north-western corner of the survey displays this division, separating the northward flowing tributaries of the Blackwood River catchment and the southward flowing drainages of the Warren-Tone and Frankland-Gordon River catchments (see Figure 2).
Native vegetation

There have been two different types of vegetation mapping in the Tonebridge-Frankland area. Smith (1972) mapped vegetation units in the uncleared portions of the western half of the Tonebridge map sheet area at 1:250,000 scale. Beard (1979) produced a map of vegetation units of all land in the remaining area at the same scale. Together these were represented as a vegetation systems map at 1:1,000,000 scale with system descriptions (Beard 1981).

The Tonebridge-Frankland area lies within three Botanical Districts of the South-western Botanical Province (Beard 1981). These include the Darling Botanical District (Menzies Subdistrict), the Eyre Botanical District and the Avon Botanical District. Beard has also recognised eight Vegetation Systems in the area (Figure 5). The following is a brief summary of the systems.

Figure 5. Vegetation systems in the survey area.
Darling Botanical District (Menzies Subdistrict)

Bridgetown System
This area includes the southern jarrah (Eucalyptus marginata) forest on ironstone gravels. It consists primarily of open forest of jarrah and marri (E. calophylla). Jarrah tends to dominate on ridges and lateritic soils, and marri is more common in valleys and on sandier soils. Marri-wandoo (E. wandoo) woodlands occur in valleys towards the eastern boundary of the system. Understorey species include bull banksia (B. grandis) with low scrub species. Downstream drainage lines feature flooded gum (E. rudis). The headwater areas tend to be open and treeless featuring tall open thickets of Hakea and Acacia and dense thickets of Melaleuca species.

Jingalup System
A combination of jarrah-marri-wandoo (Eucalyptus marginata, E. calophylla, E. wandoo) woodland occur on summit ironstone gravels. Brown mallet (E. astringens) may occur with jarrah on breakaways. On the surrounding slopes, woodland of marri and wandoo combine with jam (Acacia acuminata), sheoak (Allocasuarina huegeliana) and scattered understorey species. Flooded gum (E. rudis) is dominant on drainage lines with Melaleuca species.

Kwormicup System
This vegetation system is a mosaic of swampy plains with low sandy rises. Jarrah-marri (Eucalyptus marginata, E. calophylla) forest is the dominant overstorey on the rises. These enclose numerous patches of jarrah low-forest, paperbark low-forest or reed swamps. The flat, swampy terrain has jarrah-marri forest often mixed with yate (E. occidentalis) and wandoo (E. wandoo). Understorey species often consist of Banksia with Xanthorrhoea, Hakea and Melaleuca species in drier areas grading into reeds with scattered paperbark in the swamps.

Jarrah-marri forest in the survey area
Kendenup System
A mixed woodland vegetation system occurs across the plain drained by the Young and Kalgan Rivers to the south, and by the Gordon River to the north. It features jarrah (Eucalyptus marginata) equally combined with marri (E. calophylla). Wandoo (E. wandoo) is more important on upper slopes. Lower slopes have yate (E. occidentalis) and wandoo. Moit (E. decipiens) occurs in depressions with some tea-tree along the creeks.

Kent System
This is gently undulating, poorly drained country with numerous large swamps. Jarrah (Eucalyptus marginata) low forest is predominant. Swampy areas carry a mixed community of reeds combined with either heath shrubs such as swamp bottlebrush (Beaufortia sparsa) and spearwood (Kunzea ericifolia), or scattered paperbark trees (Melaleuca cuticularis).

Eyre Botanical District

Stirling Range System
Vegetation communities covering the Stirling Range can be considered a catena from crests to footslopes. On the summits are mixed thicket, without clear dominance, but featuring Dryandra formosa, Isopogon latifolius and Oxylobium atropurpureum as the most conspicuous species. On lower slopes, a mallee-form jarrah (Eucalyptus marginata) is common in the mallee-heath formation, merging into jarrah low woodland on footslopes. This, in combination with marri (E. calophylla), is seen in valleys, occasionally with wandoo (E. wandoo). A species-rich mallee-heath surrounds the range with blue mallee (E. tetragona) prominent.

Qualup System
This is a widespread area of mallee-heath over sandy plains, with the conspicuous blue mallee (E. tetragona) dominating. Areas of deep sands feature a scrub-heath formation with chittick (Lambertia inermis) generally replacing the mallee. The common salt lakes, pans or swampy depressions across the system have moit (E. decipiens) associations if the area is predominantly sandy or yate (E. occidentalis) if loamy. Mallee is seen on the lunettes fringing the lake areas.

Avon Botanical District

Tambellup System
This vegetation system is a dissected landscape, but with low relief. It features a few laterite capped hills or breakaways which carry woodlands of blue and brown mallet (Eucalyptus gardneri and E. astringens). Otherwise, the system is dominated mainly by wandoo (E. wandoo), which associates with yate (E. occidentalis) in various landscape positions, with yate being more common on heavier soils. Flooded gum (E. rudis) occurs more commonly around drainage lines to the west.
Previous surveys

CSIR Division of Soils in the late 1940s conducted several large-scale surveys known as spot surveys. Their purpose was to improve the knowledge of the soils in the area and to provide information on land nominated for the War Service Settlement program. The spot surveys conducted in the Tonebridge-Frankland study area include: *Kybelup Spot Survey* (Smith 1947a), *The Rocky Gully survey* (Smith 1947b), the *Progress Report on the Tone River Soil Survey* (Smith 1948) and also the *Frankland Spot Survey* (Pym 1956). *Pedogenesis in the Frankland River Valley* (Smith 1951) included information and maps from the earlier reports to represent the entire Frankland catchment.

The most widely used soil information for the area to date, however, has been Sheet 5 of the *Atlas of Australian Soils* (Northcote *et al*. 1967). It was published at a scale of 1:2,000,000 and provided a broad indication of the major soil and landform associations. This was the mapping used in two more recent publications: *An introduction to the soils of the Katanning advisory district* (Stoneman 1991) and *An introduction to the soils of the Albany Advisory District* (Stoneman 1990).

A local-scale survey in the area was an unpublished soil-landform map with legend for the Tone Reserve for the Department of Conservation and Land Management prepared by Churchward (1990).

Detailed physical and chemical data for two profiles in the Tonebridge and Frankland area were published in *Reference soils of south-western Australia* (McArthur 1991). The profiles were described from relatively undisturbed land in nature reserves or uncleared private land.

Tille and Percy (1995) described the soil-landscape zones and systems within the Blackwood River catchment, which covers the north-western corner of the area. Land resource surveys adjacent to the Tonebridge-Frankland area include the South Coast and Hinterland area (Churchward *et al*. 1988), Manjimup area (Churchward 1992), Wellington-Blackwood (Tille 1996), Katanning area (Percy 2000), and Tambellup-Borden (Stuart-Street and Marold, in prep). These survey areas are shown in Figure 6.

An extensive field data collection for the Frankland 1:100,000 map sheet area was undertaken by Gottfried Scholz (unpublished data). He collaborated to provide soil and land capability information in the Kent River Catchment (Kelly 1995), which encompassed the south-eastern corner of the survey area. More recently, Smolinski completed the soil-landscape information for the South West Forest Region under the Regional Forest Assessment process (Smolinski 1999). He also provided preliminary mapping and some field data for this current report in *Soils of the Tonebridge Area* (Smolinski unpublished data).
Figure 6. Location of other soil-landscape mapping surrounding the survey area.
Survey methods

The following procedures were used in the Tonebridge-Frankland survey:

- Previous work on the land resources (soils, vegetation and geology) of the survey area and adjacent areas was reviewed.

- A field reconnaissance survey was conducted to identify major subdivisions of mapping units to province, zone and system level.

- Preliminary map unit boundaries were identified by stereo air photo interpretation using 1:25,000 colour photos (Job No. 950019, September 1995 and Job No. 950020, September 1995).

- Sites were chosen using the free survey technique (Gunn et al. 1988) to describe soil profiles and identify their relationship to the landscape. They were also used to test and improve the conceptual models for mapping. The preliminary mapping and ease of access influenced site selection.

- Field work was undertaken between 1995 and 1999 over approximately 511,000 hectares. Mr Henry Smolinski undertook preliminary mapping and survey sites for the Tonebridge 1:100,000 map sheet. Dr Gottfreid Scholz described two thirds of the survey sites across the Frankland 1:100,000 map sheet.

- Angela Stuart-Street completed the survey sites for the Tonebridge and Frankland map sheets, and undertook mapping of the Frankland map sheet and amendments to the preliminary mapping of the Tonebridge map sheet.

- Data was collected at 1,661 sites (about one site per 310 ha) and their distribution is shown in Figure 7. At most sites, soil profiles and their environment were described using McDonald et al. (1990) and coded to Department of Agriculture standards. Soil profiles were described from pits, exposures and/or hand auger borings to a depth of 1 m, where possible. The amount of detail varied from comprehensive descriptions of soil pits (data point) to abbreviated description from auger borings (observation point). Many of the soil profiles were classified in the field using the Australian Soil Classification (Isbell 1996) and the Soil Groups of Western Australia (Schoknecht 1996).

- Data were recorded manually on site cards and later entered in the Department of Agriculture Soil Profile database.

- Soil samples were collected from 23 soil pits and exposures for chemical and physical analyses that were conducted by the Chemistry Centre of Western Australia.

- Conceptual models were developed which relate the various sources of evidence (field data, previous resource data, photo interpretation, published soil process and development models) to soil variation. A synthesis of this material was used to adjust the map boundaries and predict which soils occur within them.

- Colour aerial photographs at 1:25,000 scale were used as the mapping base. The map unit boundaries and labels were captured from these photographs using a computer aided mapping system operated on MicroStation software. The locations of the sites were determined using a Garmin GPS 75. The map unit at each site was identified from the digitised maps and has been added to the Soil Profile database where appropriate.
• Soil classifications were reviewed and updated (Isbell 2002; Schoknecht 2002).

• The map units were described in a standard format and this information has been added to the Map Unit database. The description includes the proportion of unmapped components (land units). These are combinations of WA Soil Groups (Schoknecht 2002), soil group qualifiers and landscape position. Where possible a soil series has been assigned to these land units.

• Land qualities have been assessed for each land unit within each map unit following the methodology outlined in van Gool et al. (in prep).

Figure 7. Location of field sites.
Mapping units

A map unit identifies areas with similar characteristics and properties. In the Tonebridge-Frankland survey, soil-landscape units were used to identify areas that had similar soil and landforms. Soil-landscape map units were used in this survey because large areas can be covered rapidly. The small mapping scale and low intensity of sampling did not allow individual soil units to be mapped. Soil-landscape units (e.g. soil-landscape systems) were delineated with the aid of remote sensing techniques such as interpretation of aerial photographs. They were defined on landform and the pattern of geology, soil and vegetation within the landform.

The Department of Agriculture has established an hierarchy of soil-landscape map units. The hierarchy aims, in part, to maintain a consistent approach with different scales of mapping and varying levels of complexity of soils and landscapes (Purdie 1998). Moving down the hierarchy, the map units cover smaller areas and less complexity. Each map unit (as distinct from each occurrence of the map unit) in Western Australia has a unique symbol indicating its place in the map unit hierarchy. An example of a map unit from the Tonebridge-Frankland survey is illustrated in Figure 8.

Example: 254Fh_1g indicates the map unit Frankland Hills 1 Subsystem granite outcrop phase (254Fh_1g) is in the Western Region (2), Avon Province (25), Warren Denmark Southland Zone (254), Frankland Hills System (254Fh) and Frankland Hills 1 Subsystem (254Fh_1). On the accompanying map the map unit is labelled Ph1g for better readability.

The full symbols are attached to the digital maps and are used in the Soil Profile and Map Unit databases.

Lake Unicup is one of many wetlands within the Warren-Denmark Southland Zone
1. Regions
Broad subdivisions of the Australian continent (Bettenay 1983).
e.g. The Western Region (2)

2. Provinces
Provides a broad overview of the whole state suitable for maps at scales of about 1:5,000,000 (Bettenay 1983).
e.g. The Avon Province (25)

3. Zones
Areas defined on geomorphologic or geological criteria, suitable for regional perspectives.
e.g. The Warren-Denmark Southland Zone (254)

4. Systems
Areas with recurring patterns of landforms, soils and vegetation, suitable for regional mapping at scales of 1:250,000.
e.g. Frankland Hills System (254Fh)

5. Subsystems
Areas of characteristic landforms features containing definite suites of soils, suitable for mapping at regional scales of 1:100,000.
e.g. Frankland Hills 1 Subsystem (254Fh_1)

6. Subsystem phases
Division of subsystems based on land use interpretation requirements.
e.g. Frankland Hills 1 granitic phase (254Fh_1g)

7. Land units (unmapped at regional scale)
Describe areas of land with similar soils, slopes and landforms

Figure 8. Hierarchy of soil-landscape map units used in this report.
Soil-landscape regions, provinces and zones

The Tonebridge-Frankland survey is located within the Western Region of Australia that covers most of the agricultural and pastoral areas of Western Australia excluding the Kimberley, the Sandy Desert and the Nullarbor Plain (Bettenay 1983). Avon Province covers most of the survey area. The other province (Stirling) is a small part of the east of the survey.

Avon Province

The Avon Province is a laterised plateau on Precambrian granites and gneisses, moderately dissected at the margins by rivers including the Swan-Avon and the Blackwood (Bettenay 1983). It covers most of the forest and wheatbelt as far north as about Carnamah. The northern boundary of catchments of the generally south flowing rivers between Denmark and Esperance mark its southern boundary. Within the survey are three of the eight soil-landscape zones recognised in this province (Figure 9). They are the Eastern Darling Range Zone, the Warren Denmark Southland Zone and the Zone of Rejuvenated Drainage.

Figure 9. Soil-landscape provinces and zones in the survey.


Eastern Darling Range Zone

The Eastern Darling Range Zone is a lateritic plateau on granite and gneiss with eastward flowing streams in broad shallow valleys. It is moderately stripped with areas of strong dissection. Eocene sediments occur locally in the zone. The soils are mainly formed on laterite colluvium and, in places, on weathered granite.

The zone extends north to about the Moore River and south to the Blackwood River (Tille 1996). It ranges from 20 to 70 km wide and is bounded in the west by the Western Darling Range Zone and in the east by the Southern Zone of Rejuvenated Drainage.

In the survey, the small area of the Eastern Darling Range Zone in the north-west has large remnants of undulating plateau covered by deeply weathered lateritic soils. Valleys here are dissected to the underlying granitic bedrock by the Blackwood River and its tributaries. The limit of significant stripping of the broad laterite plateau of the Southern Zone of Rejuvenated marks its southern boundary.

Forests and woodlands of jarrah (Eucalyptus marginata), marri (E. calophylla) and wandoo (E. wandoo) mainly covered the landscape. Within this survey area, the vegetation is described as the Bridgetown Vegetation System within the Darling Botanical District (Menzies Subdistrict) according to Beard (1981).

In the Tonebridge-Frankland area the Eastern Darling Range Zone (code 253) consists of the Boyup Brook Valleys and Eulin Uplands soil-landscape systems.

Southern Zone of Rejuvenated Drainage

The Southern Zone of Rejuvenated Drainage is mainly a moderately to strongly stripped erosional surface of gently undulating rises to low hills. It has continuous stream channels that flow in most years. Colluvial processes are active with most soils formed in colluvium or weathered granitic rock. Small gravelly remnants of the laterite profile remain on some hillcrests and are often flanked by moderate to steep breakaways.

The Southern Zone of Rejuvenated Drainage extends from Brookton to south of Tambellup (Percy 2000). The Eastern Darling Range Zone bounds it to the west. The Southern Zone of Ancient Drainage forms its major eastern boundary. The boundary between the Zones of Rejuvenated and Ancient Drainage roughly conforms to the Meckering Line. This imaginary line was defined by Mulcahy (1967) as marking the downstream limit of broad valley flats with salt lake chains.

Jarrah (Eucalyptus marginata) and marri (E. calophylla) woodlands predominate in the west. These are gradually replaced by woodlands of wandoo (E. wandoo), rock sheoak (Allocasuarina huegeliana) and jam (Acacia acuminata) in the east. Flat topped yate (E. occidentalis), brown mallet (E. astringens), blue mallet (E. gardneri) and flooded gum (E. rudis) are locally common. Within the survey, the vegetation was Beard (1979, 1981) as the Jingalup and Kendenup Vegetation Systems of the Darling Botanical District (Menzies Subdistrict) and the Tambellup Vegetation System of the Avon Botanical District.

In the survey area the Southern Zone of Rejuvenated Drainage (code 257) consists of the Carrolup, Farrar, Jingalup and Gordon Flats Systems.

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**Warren-Denmark Southland Zone**

The **Warren-Denmark Southland Zone** (Tille 1996) is a diverse area of extensive laterite plateau, deeply dissected valleys and a coastal plain of dunes with swampy backplains, estuaries and lakes. It begins at the Southern Ocean and rises 250-350 m above sea level on the southern edge of the Blackwood River Valley. The rise tends to occur across a series of steps or broad benches. These steps are not always clearly expressed.

This zone formed on crystalline rocks (mainly granite and gneiss) of the Yilgarn Craton and the Albany Fraser Orogen. In many areas this bedrock is overlain by a deeply weathered lateritic mantle or by sedimentary deposits dating from the Quaternary and Tertiary periods.

The Warren-Denmark Southland Zone extends 150 km from the Eastern and Western Darling Range Zones and the Southern Zone of Rejuvenated Drainage to the coastline of the Southern Ocean. It extends west to the Darling Fault, with the Donnybrook Sunkland Zone abutting the western margin, and the Stirling Province (Stirling Range Zone and Albany Sandplain Zone) defining its eastern limits.

The rainfall ranges from 550 mm in the north-east to 1,400 mm in the south-west.

In the survey a large proportion of its western part has retained a cover of native vegetation. There is significantly less in the east. Jarrah-marri (*Eucalyptus marginata*-*E. calophylla*) forests and woodlands are dominant, with karri (*E. diversicolor*) tall forest in higher rainfall areas, particularly the steeper slopes. Karri forest also occurs on islands of rocky soils interspersed with areas of sedge lands, heath lands and paperbark woodlands.

Within the survey area, the Warren-Denmark Southland Zone (code 254) includes the Manjimup Plateau, Perup Plateau, Unicup, Frankland Hills, Wilgarup Valleys, Yaraleena and Kent soil-landscape systems.
**Stirling Province**

The **Stirling Province** is a narrow strip along the Southern Ocean with “…Proterozoic gneisses and migmatites which are overlain sporadically by Tertiary marine and continental sediments” (Bettenay 1983). The northern boundary of the southward flowing drainage lines that roughly corresponds to the Jarrahdoodoo axis marks the zone’s northern limits. A small proportion of the survey is in the Stirling Province and this is entirely the Stirling Range Zone.

**Stirling Range Zone**

The **Stirling Range Zone** consists of the steep mountains of the Stirling Range (Proterozoic metasediments) and associated areas of undulating rises with granitic outcropping, and the broad poorly drained plains of the North Stirling basin. The Stirling Range Zone is bounded to the north and east by the Pallinup Zone, to the west and south by the Warren-Denmark Southland Zone and Albany Sandplain Zone, and to the north-west by the Southern Zone of Rejuvenated Drainage. It stretches approximately 100 km from east to west, and almost 50km from north to south at its widest point.

The zone is dominated by its namesake, the Stirling Range. The mountains and hills reach a pinnacle height of 1,073 m at Bluff Knoll, the highest point of the southern half of the State (Beard 1981). In the west, the hills become more rounded and subdued, with Sukey Hill at Cranbrook reaching just 373 m, and Geekabee Hill, north-east of Frankland, the outlying western-most prominence of the range, reaching 400 m. Immediately north of the main range is North Stirlings basin. This area of broad plains is formed on Eocene sediments with poorly defined drainage lines and many salt lakes (Hardy and Tille 1993). At the western flank of the range are the undulating hills and rises with conspicuous granitic outcropping of the Jaffa soil-landscape system.

The rainfall is highly variable from 600 mm in the west to 400 mm in the east, and up to 1,000 mm near Bluff Knoll. The peaks of the range can create localised weather conditions in the Zone, often as extended periods of cloud cover and drizzle, and occasional snow on the highest peaks during winter and spring.

The native vegetation across the Stirling Range forms a unique catena (Beard 1979), ranging from mixed thicket associations on the upper slopes and peaks to mallee heath on mid-slopes, and woodland of jarrah (*Eucalyptus marginata*), marri (*E. calophylla*) and wandoo (*E. wandoo*) on protected lower slopes and drainages. On the plains to the north, mallee-heath is dominant with blue mallee (*E. tetragona*) being the conspicuous species, interspersed with scrub-heath dominated by chittick (*Lambertia inermis*). Yates (*E. occidentalis*) occur in many swampy areas, along with paperbark woodlands (*Melaleuca cuticularis*) and tea-trees (*Melaleuca spp.*). The undulating rises and plains to the west of the main range support woodland remnants of wandoo, jarrah and marri, with yate.

Only the western portion of the Stirling Range Zone (code 248) occurs in the survey area, being represented by the Stirling Range, North Stirlings and Jaffa soil-landscape systems.

(Note: Since being described in Percy (2000), the definition of this zone has been amended.)
Soil-landscape systems

Sixteen soil-landscape systems have been identified in the survey (see Table 5, Figure 10). These are defined on criteria including geology, landform and soil. Table 5 lists the systems, the zones in which they occur and the area in the survey.

Table 5. Soil-landscape systems within the Tonebridge-Frankland survey and their place in the soil-landscape hierarchy.

<table>
<thead>
<tr>
<th>Province and Zone</th>
<th>System</th>
<th>Code</th>
<th>Area (ha)</th>
<th>% of survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Avon Province</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern Darling Range Zone</td>
<td>Boyup Brook Valleys</td>
<td>253Bv</td>
<td>15,842</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>Eulin Uplands</td>
<td>253Eu</td>
<td>7,409</td>
<td>1.5</td>
</tr>
<tr>
<td>Southern Zone of Rejuvenated</td>
<td>Carrolup</td>
<td>257Ca</td>
<td>32,835</td>
<td>6.4</td>
</tr>
<tr>
<td>Drainage</td>
<td>Farrar</td>
<td>257Fa</td>
<td>69,648</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>Gordon Flats</td>
<td>257Gd</td>
<td>32,408</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>Jingalup</td>
<td>257Jp</td>
<td>27,684</td>
<td>5.4</td>
</tr>
<tr>
<td>Warren-Denmark Southland Zone</td>
<td>Frankland Hills</td>
<td>254Fh</td>
<td>115,167</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>Kent</td>
<td>254Ke</td>
<td>65,030</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td>Manjimup Plateau</td>
<td>254Mp</td>
<td>13,604</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Perup Plateau</td>
<td>254Pp</td>
<td>54,849</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Unicup</td>
<td>254Uc</td>
<td>35,314</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>Wilgarup Valleys</td>
<td>254Wv</td>
<td>7,689</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Yaraleena</td>
<td>254Ya</td>
<td>22,914</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Stirling Province</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stirling Range Zone</td>
<td>Jaffa</td>
<td>241Jf</td>
<td>5,013</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>North Stirlings</td>
<td>241Nt</td>
<td>2,260</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Stirling Range</td>
<td>241St</td>
<td>2,840</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Each system in the survey has component subsystems and phases as outlined in the soil-landscape hierarchy (Figure 8). Subsystems are areas of characteristic landform features containing a defined suite of soils. Phases highlight areas where particular features (e.g. rock outcrops or steep slopes) are predominant within the general pattern. Descriptions of the systems, subsystems and phases are contained in the accompanying CD-ROM. For each system the main landforms and soils are briefly described. The regional geology is outlined along with the main vegetation types and plant species found in the system. An indication of present land use and land management issues associated with each system is also included. For each system, the subsystems and phases found in the survey are listed. A cross-sectional diagram indicates the relative heights of the landforms and the likely location of the subsystem and phases. A brief discussion about each of these systems follows including their similarities and relationships. Soil types mentioned are largely WA Soil groups (Schoknecht 2002).
In the north-west corner of the survey area, dissection by the westward flowing Blackwood River and its tributaries has occurred. The plateau remnants here are mapped as the Eulin Uplands system. This area has similar soils to the Darling Plateau, and contains extensive areas of poorly drained upland flats developed on Eocene sediments. The Blackwood and upper Tone Rivers and their tributaries have eroded the plateau creating moderate to steep-sided valleys with soils formed on weathered granitic rocks and lateritic colluvium. These areas have been mapped as the Boyup Brook Valleys system. These valleys commonly have gravels, grey deep sandy and brown deep loamy duplex soils.

The Farrar and Jingalup systems are low hills and rises with mainly Grey deep sandy duplex soils formed in weathered granite. Rock outcrops are common on hillslopes. Red loamy and sandy duplex soils and gritty Brown deep sands are associated with the dolerite and granite outcrops. The Farrar system has small remnants of laterite plateau with gravel soils, usually edged with acid duplex soils on breakaways. In the Jingalup system, these remnants are more extensive. Relief in the Jingalup system is lower than in the Farrar system, and the hillcrests are generally closer together forming distinct shallow valleys.

The Carrolup system occurs to the east of the Farrar system. It features dominantly Grey deep sandy duplex soils formed on weathered granitic rock and truncated laterite profile. A
significant proportion of soils have formed on colluvial deposits derived from weathered rock and/or laterite soil. The relief is generally more subdued than the Farrar system with gently undulating to undulating rises dominant.

The Frankland Hills system appears as dissected lateritic terrain of undulating low hills and rises with defined V-shaped valleys. It occurs largely to the south of the broad alluvial plains of the Gordon Flats system. Ironstone gravelly soils are dominant, with deep sandy duplex soils also common. The Yaraleena system, also features dissected lateritic terrain, but is formed on undulating rises and has less relief than the Frankland Hills system to the west. Like the Frankland Hills system, laterite and colluvium over granitic rocks are the dominant influences, commonly featuring ironstone gravelly soils.

Broad lateritic divides and shallow, minor valleys dominate the gently undulating surface of the Perup Plateau system. It features Loamy gravels, Duplex sandy gravels and Wet soils (sometimes saline). This area is very similar to the Manjimup Plateau system in the south west corner, but it occurs in a lower rainfall area and the valley floors are prone to salinity when cleared. The Manjimup Plateau system also features Duplex sandy gravels, Loamy gravels and Wet and Semi-wet soils. Major valleys are moderately to deeply incised into these two upland areas. They include the Perup, the lower Tone and Frankland Rivers. These form part of the Wilgarup Valleys system. Common soils here include Loamy gravels and Friable red/brown loamy earths.

A large proportion of the southern region of the Tonebridge-Frankland area is dominated by broad alluvial plains, which include the Gordon Flats, Kent, Unicup and the North Stirlings systems. The Gordon Flats system includes the floodplains of the Gordon and upper Tone Rivers and the lower reaches of Uannup Brook and Slab Hut Gully. It is dominated by deep sandy duplexes, deep sands, and Saline wet soils. The Unicup system encompasses the sub-catchment areas of Lake Unicup and Lake Muir. This area includes numerous ephemeral wetlands and swamps, with Pale deep sands and Wet soils being predominant. To the southeast of Frankland, the Kent system delineates the alluvial plains surrounding the headwaters of the Kent River. Duplex sandy gravels, Semi-wet soil and Grey deep sandy duplex soils are common here. Small lakes and swamps also occur across this system. On the eastern fringe of the study area is a small part of the alluvial plains of the internally drained basin of the North Stirlings system. This features scattered playa salt lakes and associated crescent dune ridges of fringing lunettes and is dominated by Salt lake soil and deep and shallow sandy duplexes, often with alkaline subsoils.

The westernmost extent of the hills and mountains of the Stirling Range system appears in the Tonebridge-Frankland area as the subdued prominence of Geekabee Hill, east of Frankland. This abuts the Jaffa and the North Stirlings systems. Stony soil and Duplex sandy gravel with Grey deep sandy duplex are common in the Stirling Range system. The undulating topography and adamellite and granitoid geology of the Jaffa system set it apart from the sandstone and shale of the prominent Stirling Range system it flanks. Grey deep and shallow sandy duplexes are the main soils here, and rock outcrops are common on hillslopes. The Yaraleena system, which meets the Jaffa system at its western extent, appears similar, but the proportion of ironstone gravelly soils is much higher in the Yaraleena system.
Accompanying maps

Maps are a representation of the land reality. Soils form a continuum in the landscape and therefore, unit boundaries are placed by surveyor judgement on evidence available at the scale of mapping. Rarely do boundaries indicate sharp changes, but a position where the rate of soil and landscape variation is likely to be greatest.

The Tonebridge-Frankland survey was prepared for a map production scale of 1:100,000 and is covered by two map sheets. The map legend (on the ready to print .pdf files) or the descriptions of the mapped units briefly describe the landscape and major soil (in terms of WA. Soil groups) for each map unit, usually the subsystem. Descriptions of map units apply to all occurrences in the survey and to any occurrences in adjacent surveys. Individual map units (shapes or polygons) may differ considerably from this description in terms of the proportion of different soils and landforms that occur within them. Thus the map only provides a guide to what may occur at a particular point or selected area, not a definitive statement. All map units, subsystems and phases, within each system have the same colour. The map legend is arranged alphabetically by soil-landscape system. The detailed maps can be viewed on the accompanying CD-ROM.

Gordon Flats system is one of the broad alluvial plains occurring in the survey.
Soils

The Tonebridge Frankland survey is dominated by gravelly and sandy soils. Ironstone gravels are particularly prominent in the area of intact lateritic plateau and the undulating terrain of hills and valleys that feature in the west. These give way to sandy duplex soils that dominate in the east of the survey. The main soils in the survey are described using the WA Soil Group classification (Schoknecht 2002).

Duplex sandy gravel is one of the two prominent soil groups across the area. The occurrence of this soil decreases marginally from west to east and is often found on mid to lower hill slopes, hill crests and well-drained plains. It generally appears as yellow-brown sandy gravel (with a dark grey organic surface) over a yellow or brown, sometimes mottled, clay subsoil. Loamy gravel is also quite prominent in the west of the survey. This generally appears as yellowish brown sandy loam with 20-80% of ironstone gravel in the profile, and the clay content increases gradually with depth. Loamy gravel is generally seen on upper hill slopes and hill crests. In the east, the original laterite plateau has eroded away leaving isolated gravelly hill crests or breakaways. Sandy duplex soils dominate on the slopes and the broad valley plains. Products of the eroded laterite profile are in evidence by the common presence of a thin layer of ironstone gravel at the base of the sandy subsurface soil.

Grey deep sandy duplex soils are the other prominent soil group found in the survey. They decrease in occurrence from east to west. The survey found that this soil often appears as a bleached sand or loamy sand (beneath a darker surface soil) over a mottled yellow clay subsoil at about 40 cm which is sometimes sodic or dispersive. This soil is commonly seen on mid to upper slopes across the area, and on well-drained plains.

Sandy soils dominate the remainder of the area, particularly to the south. These occur largely in broad alluvial plains mainly derived from sediments that have infilled ancient drainage systems. These poorly drained plains feature Pale deep sands with Wet and Semi-wet soils, and are interspersed with lakes and wetlands, which are common in the south of the survey.

WA Soil Groups and WA Soil Supergroups

Accurate technical communication requires standardised nomenclature. Various systems of soil classification have been used in Australia. The Australian Soil Classification (Isbell 2002) is the current standard among soil professionals. Its development involved extensive consultation. Unfortunately its application, even at its most general way, often requires information such as laboratory analyses that is not available for most users in most circumstances. It was, therefore, considered a difficult communication medium for many users of land resource data in Western Australia.

At the other end of the scale, soil names such as those based on pre-existing native vegetation have served local communities well. However, with the vegetation in many areas being long since cleared, recognition becomes more difficult. Typically, these local names are only applicable in a small area and the same names tend to be used for different soils in different areas.
Three common soils in the Survey area

Duplex sandy gravel are common across the area

Deep sandy duplex are also widespread

Loamy gravel is more common in the west of the survey
The Western Australian Soil Groups (Schoknecht 2002, also on CD-ROM) attempts to standardise naming of soils in a way that is both intuitive and minimises the need for technical analyses. Soil groups are defined within soil supergroups giving two levels of nomenclature. Soil groups are used to identify the soil component of the land resource data sets maintained by the Department of Agriculture.

Soils from 44 soil groups are recognised in the survey (Table 6). These are from all of the soil supergroups.

The most common soil groups are Duplex sandy gravel (16% of the survey area) and Grey deep sandy duplex (15%). Loamy gravel (10%) is the next most widespread. Semi-wet soil, Deep sandy gravel and Shallow gravel (each 6%) and Yellow/brown deep sandy duplex soils (5%) are the other more common soils. All other soils were found in less than 5% of the survey area.

The most common soil supergroup is the Ironstone gravelly soils, seen in approximately 40% of the area. Sandy duplexes comprise about 27%, followed by Wet or waterlogged soils (14%), Deep sands (8%), and Loamy duplexes (5%).

Using the separate map sheet areas of Tonebridge (west) and Frankland (east) as a base, some geographic trends were identified at the soil supergroup level. Ironstone gravelly soils were more important in the west than in the east with the reverse being true for the Sandy duplexes.

Ironstone gravelly soils clearly dominate in the west, being found in 46% of the area. The next most common soil supergroup here is Sandy duplex soils, which are found in just 20% of the area. In contrast these soils are equally important in the east; Ironstone gravelly soils - 33%, Sandy duplexes - 36%.

The remaining common supergroups are found more evenly across the survey. Wet or waterlogged soils have a similar occurrence across both areas. Deep sands are slightly more widespread in the west and Loamy duplex soils are more common in the east.

At Soil group level, geographic differences were also apparent. These largely reflect the differences in the supergroups. Loamy gravel is much more important in the west than in the east (Table 6). The converse is true for the Grey deep and Grey shallow sandy duplexes. Other soils occur in similar proportions.

Distribution maps of these and other common soils can be viewed on the accompanying CD-ROM.
Table 6. Supergroups and Soil groups in Survey (hectares and percent).

<table>
<thead>
<tr>
<th>Supergroup</th>
<th>WA Soil group</th>
<th>Tonebridge</th>
<th>Frankland</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>Ironstone gravelly soils 186,300 ha 39%</td>
<td>Duplex gravelly sandy</td>
<td>45,500</td>
<td>18</td>
<td>38,500</td>
</tr>
<tr>
<td></td>
<td>Loamy gravel</td>
<td>38,000</td>
<td>15</td>
<td>14,900</td>
</tr>
<tr>
<td></td>
<td>Shallow gravel</td>
<td>17,600</td>
<td>7</td>
<td>15,400</td>
</tr>
<tr>
<td></td>
<td>Deep gravely sandy</td>
<td>16,300</td>
<td>6</td>
<td>14,500</td>
</tr>
<tr>
<td>Sandy duplexes 129,300 ha 27%</td>
<td>Grey deep sandy duplex</td>
<td>23,400</td>
<td>9</td>
<td>49,600</td>
</tr>
<tr>
<td></td>
<td>Yellow/brown deep sandy duplex</td>
<td>11,500</td>
<td>4</td>
<td>14,800</td>
</tr>
<tr>
<td></td>
<td>Red deep sandy duplex</td>
<td>600</td>
<td>&lt;1</td>
<td>2,400</td>
</tr>
<tr>
<td></td>
<td>Alkaline grey deep sandy duplex</td>
<td>1,000</td>
<td>&lt;1</td>
<td>2,300</td>
</tr>
<tr>
<td></td>
<td>Grey shallow sandy duplex</td>
<td>5,300</td>
<td>2</td>
<td>15,000</td>
</tr>
<tr>
<td></td>
<td>Yellow/brown shallow sandy duplex</td>
<td>2,000</td>
<td>1</td>
<td>2,100</td>
</tr>
<tr>
<td></td>
<td>Alkaline grey shallow sandy duplex</td>
<td>900</td>
<td>&lt;1</td>
<td>2,300</td>
</tr>
<tr>
<td></td>
<td>Red shallow sandy duplex</td>
<td>300</td>
<td>&lt;1</td>
<td>1,500</td>
</tr>
<tr>
<td>Wet or waterlogged soils 64,800 ha 14%</td>
<td>Semi-wet soil</td>
<td>19,500</td>
<td>8</td>
<td>13,000</td>
</tr>
<tr>
<td></td>
<td>Saline wet soil</td>
<td>6,000</td>
<td>2</td>
<td>13,100</td>
</tr>
<tr>
<td></td>
<td>Wet soil</td>
<td>11,700</td>
<td>5</td>
<td>6,700</td>
</tr>
<tr>
<td></td>
<td>Salt lake soil</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Deep sands 39,500 ha 8%</td>
<td>Pale deep sand</td>
<td>14,900</td>
<td>6</td>
<td>7,000</td>
</tr>
<tr>
<td></td>
<td>Gravely pale deep sand</td>
<td>4,000</td>
<td>2</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Yellow deep sand</td>
<td>6,000</td>
<td>2</td>
<td>1,900</td>
</tr>
<tr>
<td></td>
<td>Brown deep sand</td>
<td>1,100</td>
<td>&lt;1</td>
<td>4,100</td>
</tr>
<tr>
<td></td>
<td>Red deep sand</td>
<td>0</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Loamy duplexes 32,500 ha 7%</td>
<td>Yellow/brown loamy duplex</td>
<td>2,600</td>
<td>1</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Red loamy duplex</td>
<td>1,100</td>
<td>&lt;1</td>
<td>6,200</td>
</tr>
<tr>
<td></td>
<td>Grey shallow loamy duplex</td>
<td>900</td>
<td>&lt;1</td>
<td>4,200</td>
</tr>
<tr>
<td></td>
<td>Acid shallow duplex</td>
<td>600</td>
<td>&lt;1</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>Alkaline grey shallow loamy duplex</td>
<td>0</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Brown deep loamy duplex</td>
<td>6,500</td>
<td>3</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td>Red deep loamy duplex</td>
<td>500</td>
<td>&lt;1</td>
<td>1,500</td>
</tr>
<tr>
<td>Loamy earths 15,000 ha 3%</td>
<td>Brown loamy earth</td>
<td>10,100</td>
<td>4</td>
<td>2,800</td>
</tr>
<tr>
<td></td>
<td>Friable brown loamy earth</td>
<td>2,400</td>
<td>1</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>Red loamy earth</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Rocky or stony soils 5,600 ha 1%</td>
<td>Bare rock</td>
<td>1,000</td>
<td>&lt;1</td>
<td>3,600</td>
</tr>
<tr>
<td></td>
<td>Stony soil</td>
<td>800</td>
<td>&lt;1</td>
<td>600</td>
</tr>
<tr>
<td>Shallow sands 2,600 ha 1%</td>
<td>Pale shallow sand</td>
<td>1,300</td>
<td>1</td>
<td>1,300</td>
</tr>
<tr>
<td></td>
<td>Yellow/brown shallow sand</td>
<td>50</td>
<td>&lt;1</td>
<td>100</td>
</tr>
<tr>
<td>Sandy earths 1,400 ha &lt;1%</td>
<td>Yellow sandy earth</td>
<td>1,000</td>
<td>&lt;1</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Brown sandy earth</td>
<td>200</td>
<td>&lt;1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Pale sandy earth</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Miscellaneous soils 200 ha &lt;1%</td>
<td>Undifferentiated soils</td>
<td>50</td>
<td>&lt;1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>150</td>
<td>&lt;1</td>
<td>0</td>
</tr>
<tr>
<td>Shallow loams 200 ha &lt;1%</td>
<td>Red shallow loam</td>
<td>200</td>
<td>&lt;1</td>
<td>10</td>
</tr>
<tr>
<td>Non-cracking clays 150 ha &lt;1%</td>
<td>Red/brown non-cracking clay</td>
<td>50</td>
<td>&lt;1</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Grey non-cracking clay</td>
<td>0</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>Cracking clays 10 ha &lt;1%</td>
<td>Hard cracking clay</td>
<td>10</td>
<td>&lt;1</td>
<td>0</td>
</tr>
</tbody>
</table>

41
Australian Soil Classification

The Australian Soil Classification (Isbell 2002) (ASC) is a national system widely used in other Australian States. Many of the soil profiles described during the survey were classified using the ASC to at least Soil Order. The Soil Orders found within the survey area are listed in Table 7 together with their apparent abundance within the survey. This also lists the WA Soil groups most closely corresponding to each Soil Order, with the most important ones being highlighted in bold. Because the ASC and WA Soil groups use different classification criteria, soils classified to a soil group are from several soil orders and so too the converse.

Chromosol is the most common Soil Order in the survey, which include many of the sandy, loamy and gravelly duplex soils. Tenosol, which includes many Ironstone gravels, and deep and shallow sandy soils, is the next most widespread. Also common across the survey is Sodosol (duplexes with dispersive subsoils). The next most widespread Soil Order is Hydrosol which includes the seasonally wet soils such as Wet soil, and Saline wet soil, and then Kandosol, which includes Loamy gravels and Sandy earths both having gradual textural increase with depth.

*Sandmining from a lunette in the Kent System.*

**Soil Group:** Yellow deep sand;  
**ASC:** Basic Arenic Yellow-Orthic Tenosol
Table 7. Australian Soil Classification Orders in the survey area.

<table>
<thead>
<tr>
<th>Order (Suborder)</th>
<th>Description</th>
<th>WA Soil groups</th>
<th>Abundance *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromosol (Yellow, Brown)</td>
<td>Texture contrast, subsoils do not disperse</td>
<td>Duplex sandy gravels, Grey deep sandy duplex, Grey shallow sandy duplex, Yellow/brown deep sandy duplex, Red deep sandy duplex, Red shallow sandy duplex, Brown deep loamy duplex, Red shallow loamy duplex, Yellow/brown shallow loamy duplex, Grey shallow loamy duplex</td>
<td>Many</td>
</tr>
<tr>
<td>Dermosol (Brown)</td>
<td>No texture contrast, subsoil well structured</td>
<td>Brown loamy earths, Friable red/brown loamy earth, red loamy earth, Grey non-cracking clays, Red/brown non-cracking clays</td>
<td>Few</td>
</tr>
<tr>
<td>Hydrosol (Redoxic, Oxyaquic)</td>
<td>Seasonally wet soils</td>
<td>Saline wet soil, Salt lake soil, Wet soil, Semi-wet soil</td>
<td>Common</td>
</tr>
<tr>
<td>Kandosol (Brown, Yellow)</td>
<td>No texture contrast, subsoil weak structure</td>
<td>Loamy gravel, Brown loamy earth, Brown sandy earth, Pale sandy earth</td>
<td>Common</td>
</tr>
<tr>
<td>Kurosol (Yellow, Grey, Red &amp; Brown)</td>
<td>Texture contrast and strongly acid subsoil</td>
<td>Acid shallow duplex, Grey deep sandy duplex</td>
<td>Very few</td>
</tr>
<tr>
<td>Podosol (Aeric, Semiaquic)</td>
<td>Podzol layer</td>
<td>Pale deep sand</td>
<td>Few</td>
</tr>
<tr>
<td>Rudosol (Leptic &amp; Arenic)</td>
<td>Minimal profile development</td>
<td>Pale deep sand</td>
<td>Very few</td>
</tr>
<tr>
<td>Sodosol (Yellow, Grey)</td>
<td>Texture contrast and dispersive subsoils</td>
<td>Alkaline grey shallow sandy duplex, Grey shallow sandy duplex, Grey deep sandy duplex, Alkaline grey deep sandy duplex, Yellow/brown shallow sandy duplex, Yellow/brown deep sandy duplex, Red shallow sandy duplex, Red deep sandy duplex, Alkaline grey shallow loamy duplex, Grey shallow loamy duplex, Red shallow loamy duplex, Yellow/brown shallow loamy duplex, Brown deep loamy duplex, Red deep loamy duplex</td>
<td>Common</td>
</tr>
<tr>
<td>Tenosol (Sesqui-nodular, Bleached-orthic, Yellow-orthic)</td>
<td>No texture contrast, weakly developed B horizons</td>
<td>Shallow gravel, Deep sandy gravel, Pale deep sand, Gravelly pale deep sand, Brown deep sand, Yellow deep sand, Red deep sand, Pale shallow sand, Yellow/brown sand</td>
<td>Many</td>
</tr>
</tbody>
</table>

* Very few (<2%); Few (2-10%); Common (10-20%); Many (20-50%), Abundant (50-90%), Very Abundant (>90%)
Interpretation of land resource survey results

A major output of this land resource survey was to identify major soil management, soil conservation and degradation issues in the region, and outline the implications of these for land use and land management (van Gool et al. in prep). This section outlines the methodology used to assess these issues and for each a summary of the significance of these in the survey area.

Land Units and Land Qualities

To facilitate interpretation of the survey results including area summaries, each soil-landscape map unit has had unmapped land units proportionally attributed to them. Land units are areas of common landforms and similar soils found at similar points in the landscape (van Gool et al. in prep). For the purpose of the attribution, these are defined as combinations of WA Soil group, a soil group qualifier (Schoknecht 2002) and landscape position. The data attribution model assumes that a land unit is independent of a map unit, i.e. the same land unit can occur in more than one map unit. It is acknowledging that there will be real regional variation in a land unit’s characteristics. Therefore, it is assumed that a land unit is consistent within a soil-landscape zone, but may vary between zones.

Land qualities are attributes of the land and soil that affect its capability for a specified use in a distinct way (FAO 1983). Some land qualities are specifically soil related such as water repellence or susceptibility to subsoil acidification. However, most qualities such as wind and water erosion risks are both soil and landscape dependent. A few qualities are largely landform dependent, regardless of the soils present, such as flood risk.

Therefore, each unmapped land unit in the Tonebridge-Frankland survey area has been assigned a value for each of the land qualities. These can be viewed on the CD-ROM through the mapped units. In that format, definitions of all land qualities are provided.

During the Tonebridge-Frankland survey, the major land management constraints or degradation issues observed were waterlogging, subsoil acidification, water erosion, salinity, wind erosion, water repellence and subsurface compaction. The circumstances of these are outlined below. For all but salinity and subsurface compaction, an interpretation map has been prepared indicating the apparent distribution of the most adverse state (condition) for each quality. These are available on the interactive maps on the CD-ROM.

Waterlogging and inundation

Waterlogging is an excess of water in the root zone accompanied by anaerobic conditions. Inundation is ponding on the soil surface (Moore and McFarlane 1998). While this problem is widespread across the survey area, there is variable severity from season to season, from year to year and from soil-landscape system to system.

The systems that are particularly susceptible to waterlogging and inundation can be seen on the distribution map on the CD-ROM. They are the low-lying alluvial plains of the Unicup and Gordon Flats systems, as well as the Kent and North Stirlings systems. The undulating
Perup and Manjimup Plateau systems and the Boyup Brook Valleys and Eulin Uplands systems are also susceptible in small areas. In the remaining areas, the lower slopes and valleys are often subject to seasonal waterlogging and inundation, and seasonally perched watertables commonly occur in many landscape positions.

**Surface and subsurface soil acidification**

Field assessments during the survey showed that surface and subsurface acidity were generally slightly to very strongly acid (pHw 6.5-4.5) across the area. While acid soils occur naturally in our environment, Dolling *et al.* (2001) stated that most acidity has been caused by agriculture. Agriculture increases the amount of acid entering the soil, and, therefore, increases the rate of pH decline. This is due mainly to the addition of acid fertilisers, increased nitrate leaching and export of produce. Low pH values in the subsurface (10-20 cm) are more serious than low pH values in the surface soil (0-10 cm) because it is more difficult to correct the pH at depth.

A compounding concern with low pH soils can be accompanying high concentrations of potentially toxic aluminium (Al$^{3+}$) as reported in Moore *et al.* (1998a). As pH declines below about 5, Al$^{3+}$ commonly increases. To date, chemical analyses performed on selected profile samples across the area show that levels of Al$^{3+}$ (extractable in CaCl$_2$) are mainly moderate to low. This suggests that the effects of acidification are not yet as serious as in some wheatbelt areas.

The distribution map included on the CD-ROM indicates the highest proportion of highly susceptible soils to subsurface acidification hazard occur in the Unicup, Gordon Flats, Carrolup, Farrar and Kent systems. In remaining areas, significant proportions of land are also highly susceptible.

**Water erosion**

The incidence of water erosion is influenced by many factors including rainfall erosivity (intensity), soil erodibility, slope angle, slope length and management practices (Coles and Moore 1998). As discussed in van Gool *et al.* (in prep), erosion is highly variable depending on seasonal and climatic factors, with most soil loss occurring from a small proportion of areas. One of the bigger erosion risks in the area is rainfall erosivity where intense rainfall from summer or winter storms can result in large soil losses. Another important influence in this region is the slope angle, as in general the steeper the slope, the greater the erosion (Coles and Moore 1998).

Flooding is an infrequent but severe event. Thus areas that flood have, by definition, a high water erosion hazard. Such areas include the broad valley floors, saline stream channels and drainage lines of the Gordon Flats, Carrolup, Kent, Perup Plateau, Manjimup Plateau, Wilgarup Valleys and Boyup Brook Valleys systems. Steeper slopes in the Frankland Hills system adjacent to major river channels are particularly susceptible, as indicated on the Water erosion map included in the CD-ROM. Undulating topography with slopes greater than 3% of much of the Tonebridge-Frankland region makes many areas of soil-landscape systems including Jingalup, Manjimup, Perup, Yaraleena, Farrar and Jaffa highly susceptible to water erosion.
Salinity

Salinity can be classified as either primary (naturally saline areas) or secondary (salinity from evaporation of saline ground water often after excessive land clearing). For the Tonebridge-Frankland survey, secondary salinity predominates.

The increased groundwater recharge in cleared agricultural landscapes and subsequent salt mobilisation from rising groundwater has led to salinisation in many locations. However, the rainfall gradient across the region results in variability in the severity of salinity impacts from west to east. The south-western corner experiences the highest rainfall and lowest evaporation. Because of leaching by the high rainfall here, the incidence of salinity problems is low. Waterlogging and water erosion are bigger risks. Further east towards the central part of the study area where the rainfall is lower, the problems of salinity on valley floors is greater and saline seeps are present on some hillslopes. The severity of degradation is still mitigated in this region compared to what it is further east. This is due to salt removal by moderate leaching of higher rainfall and effective drainage lines. Finally, to the north-east and east is an area of lower rainfall and higher evaporation, and broad valley floors. Many of the valley floors have become saline because of the rising groundwater levels. Saline hillside seeps are also a problem.

The soil-landscape systems which are currently most affected by degradation from salinity include Gordon Flats, Carrolup, Kent, North Stirlings, Farrar and Jaffa, particularly in the valley floors, floodplain and lower slope areas. Hydrogeology assessments undertaken by Smith (1997) and De Silva (2000), indicate that the groundwater salinity levels are high to extreme in the upper Tone River area in the Gordon Flats soil-landscape system, and also areas within the Unicup system (Smith et al.2004 and New et al.2004). Smith (1997) has also identified the upper Kent catchment in the Kent system as being one of the areas that has accumulated a great deal of salt. The groundwater salinity level for the large part of the remaining area is moderately to highly saline.

The study of acidic groundwater in the Muir-Unicup area by Smith et al. (2004) has also highlighted risks of drainage as a salinity management option.

Wind erosion

A soil’s susceptibility to wind erosion can be assessed from its texture, surface condition, and landscape position. Highly susceptible soils have a loose surface condition. Being on a prominent landscape position amplifies any susceptibility. Windbreaks and/or maintenance of adequate vegetative cover (van Gool et al. in prep.) are protection from erosion. Unprotected, loose soils can blow from winds as low as 28 km/hr (Moore et al. 1998b). Gravelly soils (greater than 50% surface cover) are at reduced risk due to the physical protection of the surface lag and increased roughness that reduces the wind velocity at the soil surface.

Wind erosion can have many adverse effects including sand blasting of crops, loss of soil nutrients and associated losses in productivity and a source of air pollution and eutrophication of water bodies. In extreme events, soil can bury fences and roads, and fill dams. Wind erosion events occur infrequently.
Because past management is an important factor, wind erosion hazard indicates susceptible areas, not currently eroded/ing areas. Areas with a high to extreme wind erosion hazard are presented in the CD-ROM. The systems exhibiting the areas at highest risk include Unicup, Carrolup and Gordon Flats systems. Perup Plateau, Yaraleena and Kent systems display moderate levels of land with high to extreme risk.

**Water repellence**

A soil’s susceptibility to water repellence is related to the surface area of soil particles and the supply of water repellent compounds which varies with land use and the productivity of the agricultural system. The soils which are most susceptible to water repellence have the sandiest topsoils with less than 2% clay, particularly pale grey sandy topsoils. Other sandy surfaced soils are moderately susceptible to water repellence. They are more likely to develop water repellence when organic matter levels increase under long-term clover dominant pasture or on sheep camps.

Water repellence affects the wetting pattern of soils, resulting in uneven wetting in topsoils with patches of dry soil occurring amongst the patches of moist soil. This leads to poor germination of crops and pastures. Additionally, it may also contribute to water erosion (sheet flow) due to reduced infiltration and increased run-off. This typically occurs in heavy rain at the break of season or in summer storms.

The distribution of soils highly susceptible to water repellence across the study area is presented on the CD-ROM. The areas displaying soils with the greatest susceptibility include Unicup, Gordon Flats, Carrolup and Kent systems.

**Subsurface compaction**

Soil compaction is the reduction in soil pore size and total pore space through applied stresses, particularly wheeled vehicular traffic. This creates a compacted layer commonly referred to as plough or traffic pans. Plough pans are generated from repeated tillage and are found in medium and fine-textured soils just below the tilled layer. Traffic pans occur deeper in the soil and are caused by the compression due to traffic. The most susceptible soils have low organic carbon (<2%) and loamy sand to sandy loam textures at between 10 and 50 cm.

Soil compaction restricts root elongation and results in reduced soil volume available for water and nutrient uptake (van Gool *et al.* in prep.). It can cause a significant energy impost on tillage equipment.

Most susceptible in the survey are many of the deep sandy and loamy duplexes, sandy and loamy earths and deep sands which are all common. The Farrar, Carrolup, Unicup, Gordon Flats, Jaffa and North Stirlings systems all contain large areas of these susceptible soils.
Acknowledgments

The Tonebridge-Frankland survey was funded as part of a larger project ‘Rocky Gully – Tambellup–Borden–Nyabing Land Resources Survey’ under the National Soil Conservation Program from 1994 to 2002 as part of the National Landcare Program. Contributions were made from the Commonwealth and Western Australian Governments and administered by the Department of Agriculture. Many people have contributed to the survey to produce the information for this report, and thanks go to all of them. They include:

- Henry Smolinski undertook the original mapping of the Tonebridge 1:100,000 map sheet (2230-III) and the preliminary sites for the soil survey. Gottfried Scholz completed the major part of the soil survey of the Frankland 1:100,000 map sheet.

- John Wagnon, Jo Wheeler, David Stapleton, Barry Beard and John Grant provided valuable technical support in the field survey and were responsible for assistance with describing and sampling soils.

- John Wagnon, Barry Beard and Mary D’Souza entered profile information into the WA Soils database.

- Zaklena Sazdova, James Ross and Kus Kuswardiyanto digitised the mapping. Phil Goulding prepared the maps for publication.

- Numerous farmers permitted access to their properties for sample collection.

- Staff of the Government Chemistry Centre undertook laboratory analyses of soil samples.

- Heather Percy, Brian Purdie, Noel Schoknecht, Ted Griffin, Peter Tille, Timothy Overheu and other members of the Natural Resources Assessment Group provided invaluable assistance and advice at various stages of the survey.

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- Staff at the Manjimup office of the Department of Conservation and Land Management provided permission to access restricted forest areas during the survey.

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- The digital CD-ROM is based on AgMaps Land Profiler concept developed under the direction of Ian Kinnimonth. Tony Leeming and Ted Griffin prepared its current form with valuable technical development from Gary Spencer of Intergraph Corporation. The map window was based on an Honours project of Phil Goulding who prepared the GeoMedia warehouse and created the cgm files.
Glossary

Adamellite: A form of granite with roughly equal calcium and potassium-bearing minerals.

Alluvium: Material transported and deposited by flowing water such as rivers.

Apedal: Structureless soil with no observable peds.

*Apedral massive:* Describes a soil which is coherent and separates into fragments when disturbed. These may be crushed to ultimate particles.

*Apedral single-grained:* Describes a soil that consists of loose, incoherent particles.

Archaean: Represents the period of time about 2,700 million years ago.

Cainozoic: Represents the period of time from about 65 million years ago to the present.

Colluvium: Materials transported and deposited by gravity.

Conglomerate: A group of sedimentary rocks consisting of rounded and sub-rounded particles, many greater than 2 mm in diameter.

Craton: Major structural unit of the Earth's crust, consisting of a large stable mass of rock.

Crystalline rock: An igneous or metamorphic rock such as granite or gneiss.

Dispersive: A soil which displays the complete breakdown of aggregates into primary particles of sand, silt and clay when saturated.

Dolerite: A medium-grained basic igneous rock that has crystallised near the surface, typically occurring as a dyke, sill or plug.

Diorite: A granular igneous rock consisting essentially of feldspar and hornblende.

Duplex soil: A soil with a sudden increase in texture between the topsoil and subsoil, e.g. a sand over a clay.

Dyke: A sheet-like body of igneous rock cutting across the bedding or structural planes of the host rock. They typically appear on the surface as relatively narrow, linear features.

Earthy fabric: The soil material is coherent and characterised by the presence of pores and few if any peds.

Eocene: The epoch of the Tertiary period between the Palaeocene and Oligocene epochs.

Ferricrete: A layer of material strongly cemented by iron which looks like rock. Formed in laterite and often called sheet laterite, ironstone caprock or duricrust.

Gabbro: A coarse-grained basic igneous rock similar to dolerite.

Gneiss: Banded rocks which are generally coarse-grained and formed through high grade regional metamorphism.
Granite: A coarse-grained igneous rock consisting essentially of quartz (20 to 40%), feldspar and very commonly mica.

Granulite: A metamorphic rock of regional origin having granular texture; usually consisting of feldspars, pyroxenes and garnets.

Halophyte: Salt-tolerant species of plant such as samphire.

Hardsetting: Describes a soil which is compact, hard and apparently apedal when dry, but softens on wetting.

Horizons: A term used to describe individual layers in a soil profile. Each horizon has morphological properties different from those above and below it.

Igneous rock: Formed from magma which has cooled and solidified at the earth’s surface or within the earth’s crust.

Indurated layer: A layer of material hardened by cementation or pressure.

Laterite: Residual materials, thought to be formed in past tropical environments under climatic extremes of wet and dry seasons throughout the year. Leaching of the profile removes sodium, potassium, calcium and magnesium ions. Iron oxides remain to form a hardened and cemented layer. The lateritic profile typically consists of sand or gravel on top of a ferruginous duricrust where the iron oxides have accumulated. This overlies a mottled clay and then a pallid zone (white clay) from which the leaching has occurred.

Loam: A medium-textured soil of approximate composition 10 to 25% clay, 25 to 50% silt and less than 50% sand.

Loose: Describes the condition of an incoherent mass of individual soil particles or aggregates easily disturbed by pressure of forefinger.

Lunette: A crescent-shaped dune at the margin of a lake. The sediments originate from the floor of the lake during dry periods. They are formed by wind action.

Metamorphic rocks: Rocks such as gneiss which have been altered by heat and/or pressure.

Migmatite: Rock composed of two sources: the metamorphic host rock and an invading granitic material.

Orogen: A tectonic belt characterised by regional metamorphism and abundant plutonic intrusion.

Pallid zone: White to pink kaolinitic clay formed in the lower part of the lateritic profile. See laterite above.

pH: A measure of the acidity or alkalinity of the soil which can range from 1 to 14. Most plants grow best when the soil pH is in the range of 5.5 to 8.0.

Phyllite: A cleaved metamorphic rock having affinities with both slates and mica.
Physiography: A broad term used to refer to the general shape of the land surface.

Plateau: A level to rolling landform pattern of plains, rises or low hills standing above a cliff or escarpment.

Peds: Natural soil aggregates consisting of primary soil particles held together by cohesive forces or secondary materials such as iron oxides, silica or organic matter.

Blocky peds are cube-shaped with six relatively flat, roughly equal faces.

Crumb peds are small (1 to 5 mm diameter) soft, porous and more or less rounded. They are usually bonded by organic matter.

Polyhedral peds have an uneven shape with more than six faces.

Rough-faced peds have smooth, sometimes shiny, surfaces.

Smooth-faced peds have smooth, sometimes shiny, surfaces.

Podzol: Soils with B horizons dominated by the accumulation of compounds of organic matter, aluminium and/or iron.

Quartzite: A metamorphosed rock where the constituent grains recrystallise and develop an interlocked mosaic texture, with little or no trace of cementation.

Rooting condition: Refers to the soil volume available for plant roots and the mechanical impedance to root development. Soil volume can be reduced by rock and gravel content, by dense pans and clay layers. Plants have varying ability to explore the soil profile. Restrictions to root growth reduce moisture and nutrient availability.

Salinity: Usually refers to condition of high level of soluble salts, especially sodium chloride, in water or a soil profile. High salt levels in the soil water increase the osmotic pressure and reduce the plants ability to take up moisture. Salinity in the soil profile can come from rising saline groundwater and by addition of water with low to moderate levels of salt, which is concentrated as the water evaporates. Primary salinity refers to soils and landscapes which were saline in their virgin or uncleared state. Secondary salinity is the development of salinity after clearing and is associated with the presence of saline groundwater.

Sandy fabric: Sand grains provide the characteristic appearance of the soil mass.

Saprolite: Soft, more or less decomposed rock remaining in its original place.

Schlerophyll: Hard-leaved evergreen trees and shrubs adapted to Mediterranean climates.

Sedimentary deposits: Materials which have been moved from their site of origin by the action of wind, water, gravity or ice and then deposited. When these materials become consolidated and hard they are known as sedimentary rocks.

Silcrete: Strongly indurated siliceous material.

Sodic: Description of a soil where the B horizon has an exchangeable sodium percentage (ESP) of more than 6. Sodic soils can be structurally unstable and plant growth may be adversely affected.
Structured: Describes a soil that contains peds.

Subsoil: Layer/s of a soil below the topsoil which are usually higher in clay and lower in organic matter than the topsoil. Often called the B horizon/s of a soil profile.

Swale: A linear, level floored open depression excavated by wind or formed by the buildup of two adjacent ridges. Typically associated with the depression between adjacent sand dunes.

Tertiary: Represents the period of time from about 65 to 1.8 million years ago.

Texture: The proportion of sand, silt or clay particles in the soil, defining the coarseness or fineness of the soil material as it affects the behaviour of a moist ball of soil when pressed between the thumb and forefinger.

Texture contrast: Soil profiles that are dominated by the mineral fraction with a texture contrast of one and a half texture groups or greater between the A and B horizons. Horizon boundaries are clear to sharp.

Topsoil: Surface layer/s of a soil which are usually higher in organic matter (at least at the surface) and lower in clay than the lowest layers (subsoil). Often called the A horizons of the profile.

Weathering: The physical and chemical disintegration, alteration and decomposition of rocks and minerals at or near the earth’s surface by atmospheric and biological agents.

Well graded: Applies to soils which have a range of particle sizes, cf. poorly graded which have a narrow range (see Figure 4.2.2 in Needham et al. 1998).
References and Further Reading


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Laurie, M. (1994) Frankland to the Stirlings, Shire of Cranbrook


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Appendix 1. Laboratory analysis of soils

Samples of the most common soil types were submitted for physical and chemical analysis to the Chemistry Centre of Western Australia. For description of analytical methods see Overheu et al. 1993 p. 93. Abbreviations used in the tables are as follows:

- **Al (CaCl₂)**: Aluminium (Al) extracted in 0.01M CaCl₂
- **CaCO₃**: Calcium carbonate, soluble in dilute acid
- **CEC**: Cation Exchange Capacity
- **Exchangeable cations**
  - **Al**: Aluminium
  - **Ca**: Calcium
  - **Mg**: Magnesium
  - **Mn**: Manganese
  - **K**: Potassium
  - **Na**: Sodium

Three methods were used depending on the soil pH:

a. Soil pH 6.5-8.0, extracted in 1M NH₄Cl pH 7.0
b. Soil pH <6.5, extracted in 0.1M BaCl₂
c. Soil pH >8.0, extracted in 1M NH₄Cl pH 8.5

- **EC (1:5)**: Electrical conductivity (1:5) at 25°C
- **K (HCO₃)**: Potassium extracted in 0.5M NaHCO₃ (1:100)
- **Org C W/B**: Organic carbon, Walkley and Black method
- **P HCO₃**: Phosphorus, extracted in 0.5M NaHCO₃ (1:100)
- **P PRI**: Phosphorus Retention Index
- **P Total**: Phosphorus, total
- **Particle size analysis**: Separation of particles less than 2 mm in diameter
- **pH H₂O 1:5**: pH measured in water
- **pH CaCl₂**: pH measured in 0.01M CaCl₂
- **N Total**: Nitrogen, total
- **%**: per cent
- **me%**: milliequivalents per cent (milliequivalents per 100 g of soil)
- **mL/g**: millilitres per gram
- **mS/m**: milliSiemens per metre
- **ppm**: parts per million
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