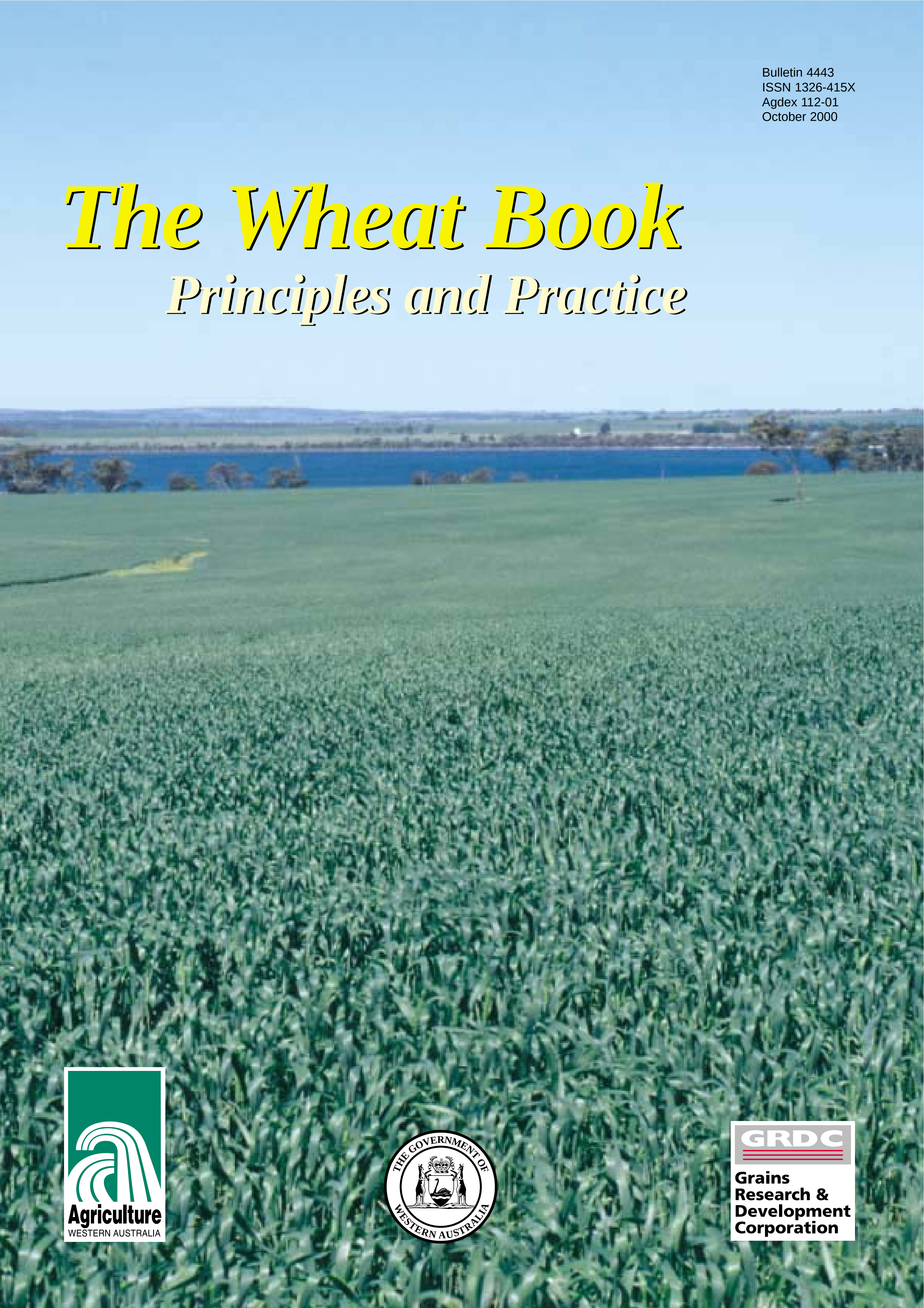

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The Wheat Book

Principles and Practice

Agriculture WESTERN AUSTRALIA

THE GOVERNMENT OF WESTERN AUSTRALIA

GRDC Grains Research & Development Corporation

The Wheat Book

Principles and Practice

Compiled by W.K. Anderson and J.R. Garlinge

Agriculture Western Australia

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The second edition of The Wheat Book has been somewhat changed from the original edition. Some of the authors of the chapters of the first edition have moved on or were no longer available to revise their contributions. The editors and authors of the second edition acknowledge the original contributors, especially Michael Perry and Brian Hillman who edited the first edition. Some of the chapters in the second edition are revisions of the original chapters and in these cases the original authors are acknowledged at the start of each chapter.

There are some new chapters or sections on weed management, grain quality, marketing, durum wheat, feed wheat and triticale and several chapters have been considerably expanded. All chapters have been revised to include new information where applicable.

The reaction from readers of the first edition of The Wheat Book has indicated that major users have included consultants, company agronomists, undergraduate students, technical specialists in machinery companies, seed merchants and fertilizer companies, in addition to wheat growers. As a consequence we have decided to slightly change the emphasis of the second edition from "A technical manual for wheat producers" to "Principles and practice of wheat production" to accommodate this wider group of users.

The Grains Research and Development Corporation has funded the printing costs of the second edition. Most of the authors are employed by Agriculture Western Australia and most have contributed their time and talents as an extra-curricular activity.

W. K. Anderson and J. Garlinge (editors)

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CHAPTER ONE
ENVIRONMENT

Chapter Coordinator: Ian Foster
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GLOBAL CIRCULATIONS AFFECTING WEATHER IN SOUTH-WESTERN AUSTRALIA

John Cramb
Western Australian Regional Office, Bureau of Meteorology

The climate of Western Australia's wheatbelt is strongly influenced by the position of a band of high pressure known as the sub-tropical ridge. An example is presented in Figure 1.1.

This ridge, which circles the hemisphere, separates the easterlies and the westerlies. The sub-tropical ridge moves north and south each year in response to the movement of the zone of maximum solar heating in the tropics. On average, the axis of the sub-tropical ridge is farthest south in the summer, well to the south of Albany. In winter it reaches its northern-most average latitude, near Geraldton.

The fundamental energy source that drives all atmospheric circulations is the unequal heating of the earth's surface by the sun. The earth's wind patterns and weather systems re-distribute energy from the hotter to the colder latitudes.

Warm, energy-laden air rises over the tropics, travels away from the equator in the upper atmosphere, then sinks back towards the surface forming the sub-tropical ridge. The sinking motion creates a warm, dry air mass, except in a relatively shallow layer close to the surface, where the character of the air is determined more by the nature of the surface over which it has been passing. The result is mostly fine weather under the sub-tropical ridge, frequently with clear skies, though cloud or fog may result if the trajectory of the air near the surface has allowed it to become sufficiently moist.

The sub-tropical ridge is not a continuous band, but rather consists of a number of discrete high pressure cells - the highs we usually see on the weather map - separated by areas of lower pressure. These low pressure areas may allow the ridge to be penetrated by air from the north or the south, to disturb the weather.

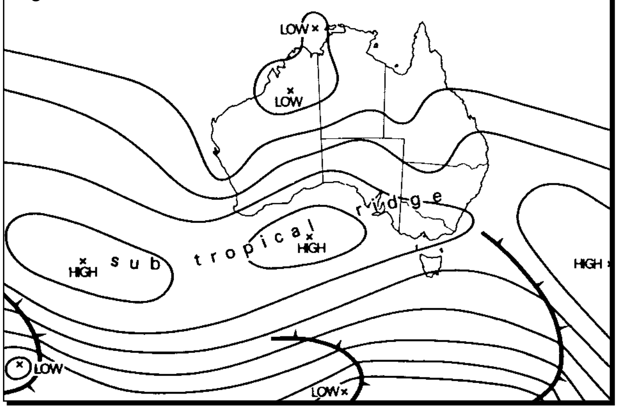
The easterlies

In a broad band extending north from the ridge, the air flow near the surface is generally from the south-east. These are the trade winds, which extend back into the tropics to complete the cycle, rising again with renewed energy. Over land, these winds are more variable in direction and are often referred to as simply 'the easterlies'. This is the normal regime that prevails over the wheatbelt throughout the summer and over the northern wheatbelt for much of the winter as well.

The easterlies assume the characteristics of the surface over which they have been passing, usually becoming hot and dry in the summer and cool and dry in the winter, but with variations well know to those who live in the area. Above the surface, the atmosphere is generally stable so fine weather is the norm but occasional disturbances occur.

Some of these disturbances originate deep in the tropics - such as decaying tropical cyclones moving south. More

Figure 1.1



A typical summer weather map showing the sub-tropical ridge to the south of Western Australia.

common are the 'upper air disturbances', which originate from upper-level westerlies, and the 'cut-off lows', which are lows that have either developed downwards from upper-air disturbances or else moved out of the surface westerlies further to the south.

Even more common in the wheatbelt, however, are those disturbances forming in the west coast trough, which develops during the warmer months because of the contrast in air density across the west coast, as the air is heated over the land and cooled over the sea. The west coast trough is associated with most of the weather changes throughout the warmer part of the year.

The westerlies

To the south of the sub-tropical ridge, the air flow varies mostly between north-west and south-west. Because of their maritime origin, the westerlies are usually cool and moist as they reach our coast, though they become drier as they progress inland.

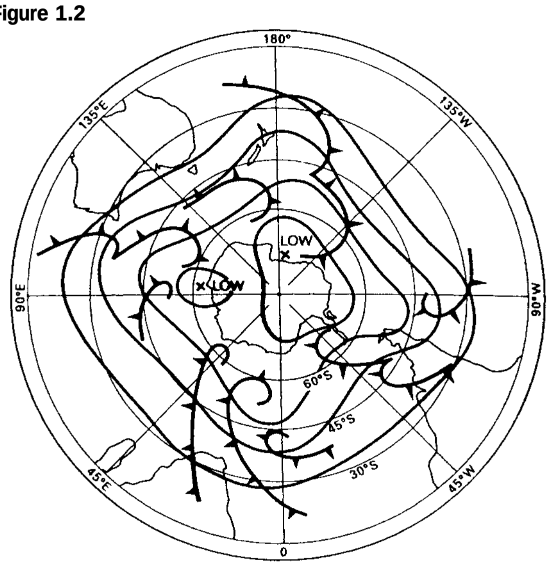
Atmospheric disturbances are much more common in the westerlies, with cold fronts passing through perhaps twice a week or more in winter. The density contrasts in the westerlies form a ready energy source for the development of depressions, and of the cold fronts which mark the boundaries of new bursts of cold air.

The main process by which the atmosphere achieves the necessary energy transfer from north to south across the westerly zone is different to that used in the tropics. Because of the rotation of the earth, the large-scale convection cells that operate between the deep tropics and the sub-tropical ridge are unable to extend all the way to the poles. Instead, the westerly flow above the surface meanders, forming giant waves which are called planetary waves or simply long waves. Energy-laden air, warm and frequently moist, is transported pole-ward ahead of the long wave troughs, while cold air moves north to the west of the troughs.

The waves can often be detected in the pressure patterns on the surface weather map for the hemisphere,

■ GLOBAL CIRCULATIONS AFFECTING WEATHER IN SOUTH-WESTERN AUSTRALIA *(continued)*

Figure 1.2



A representation of upper level wind flow around the southern hemisphere. A long wave trough is positioned just to the west of Western Australia.

particularly if pressures are averaged over a few days. However, the waves are really to be found in the stronger westerly flow at higher levels in the atmosphere, where they are usually easy to distinguish on charts of wind flow or pressure pattern.

There are normally about three or four long waves around the southern hemisphere. There is no stable configuration, so the pattern keeps changing. They usually move from west to east, but occasionally move the other way, particularly if the spacing between the troughs becomes large. They almost always move more slowly than the individual cold fronts and can sometimes persist in an area for weeks. Because they have a strong steering influence on the fronts, they often give a useful indication of the likely weather some days ahead.

Thus, if there is a long wave trough near the west coast of Western Australia in winter, it is likely that cold fronts will continually move up towards the area, causing persistent rainfall events over the wheatbelt. When there is a long wave ridge in our longitudes, individual fronts, if they arrive at all, are likely to be relatively weak.

Figure 1.2 illustrates a four-wave pattern in the upper level flow around the southern hemisphere, with one of the long wave troughs just to the west of Western Australia and a long wave ridge over eastern Australia. The possible surface positions of cold fronts are marked.

Even though the westerlies spawn most of the rain-generating disturbances affecting the wheatbelt, those systems that produce the greatest rainfalls usually derive their moisture from the tropics. Warm air can hold much more water vapour than cold air. This is basically why it rains at all - air that is forced to rise can be cooled until its moisture condenses and falls out.

A good rain producing system will have a combination of the following conditions in as great a measure as possible:

- The air will be moist through a great depth of the atmosphere;
- The lifting process will be strong, and
- The lifting process will be sustained.

The first condition is found particularly in northerly and north-westerly air-streams above the surface, with much water vapour of tropical origin being brought south, ahead of a disturbance such as a cold front approaching from the west. This southward movement of tropical air may be rapid.

Strong lifting is found particularly near the deep lows and strong fronts that form the westerlies. The third ingredient - prolonged lifting - is usually found in large and/or slow-moving systems. Fronts whose progress has been arrested or cut-off lows north of the ridge axis are especially favourable, even though they may not be very strong.

Long range weather forecasting

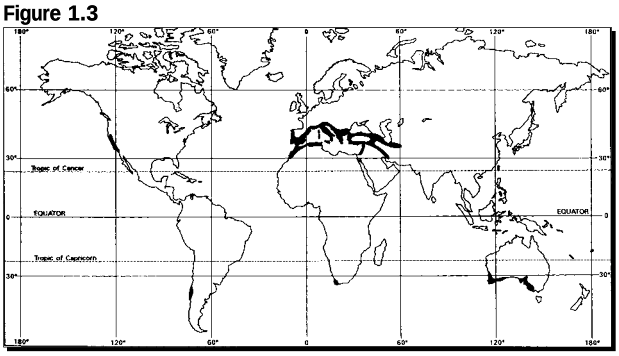
The motions of the atmosphere are particularly complex, and make the task of long range forecasting particularly difficult. Computer models, working with enormous amounts of meteorological data such as temperatures, humidities and pressures from around the globe can solve the equations describing the motions of the atmosphere. These models are continuing to improve our ability to forecast the weather up to a few days ahead.

Longer range forecasting, months or seasons ahead and extending out to the scale of decades is receiving intense scientific effort. It is crucial that longer-term climate trends be investigated, particularly those that may result from human activities. We are currently unable to give clear answers to the important questions concerning the likely nature of long-term climate changes in specific areas such as the wheatbelt. Unfortunately, such are the complexities of the problems involved, it could well be many years yet before this can be done with confidence.

■ CLIMATE IN RELATION TO AGRICULTURE IN SOUTH-WESTERN AUSTRALIA

John Cramb
Western Australian Regional Office, Bureau of Meteorology

Figure 1.3



Mediterranean climates of the world.

Located in the middle latitudes (30 to 40°S) the agricultural areas of south-western Australia have a dry-summer sub-tropical (Mediterranean) climate similar to the Mediterranean basin, southern California, Chile and the western tip of Cape Province, South Africa (see Figure 1.3).

Weather patterns in these regions are dominated by the influence of the dry, subsiding air masses of the sub-tropical ridge. In summer, as the ridge moves poleward, the climate has the characteristics and consistency of the dry tropics; while in winter it features the changeability of weather from the passage of the cyclonic circulations and cold fronts embedded in the westerlies.

The three characteristics of all Mediterranean climates (and expressed particularly strongly in south-western Australia) are:

- A concentration of the rainfall in the winter season, with the summers being nearly, or completely dry;
- Warm to hot summers and mild winter; and
- High solar radiation, especially in summer.

The most important climatic elements influencing wheat production are rainfall, solar radiation and temperature. These, both directly and indirectly (for example, through waterlogging), determine crop growth and grain yield.

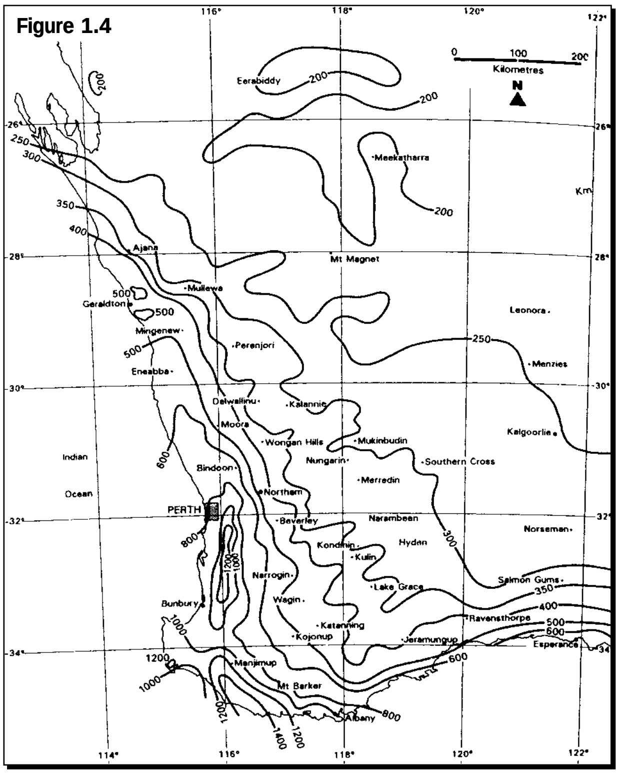
Rainfall

Annual rainfall decreases rapidly from about 1200mm on the south and south-western coasts to about 250mm at the inland limit of agriculture. The distribution is shown in Figure 1.4.

Most wheat is produced in areas with less than 500mm annual rainfall and over 40% of production is from areas receiving 325mm or less.

Rainfall distribution peaks sharply in mid-winter, especially in the west and north-west wheatbelt. Geraldton and Wongan Hills receive over 80% of their annual rainfall in the winter growing season. Usually, 60 to 70% of annual rainfall is received between May and October, the proportion of growing season rainfall decreasing to the east. The growing season rainfall for certain wheatbelt centres is listed in Table 1.1.

Figure 1.4



Distribution of annual rainfall in south-western Australia.

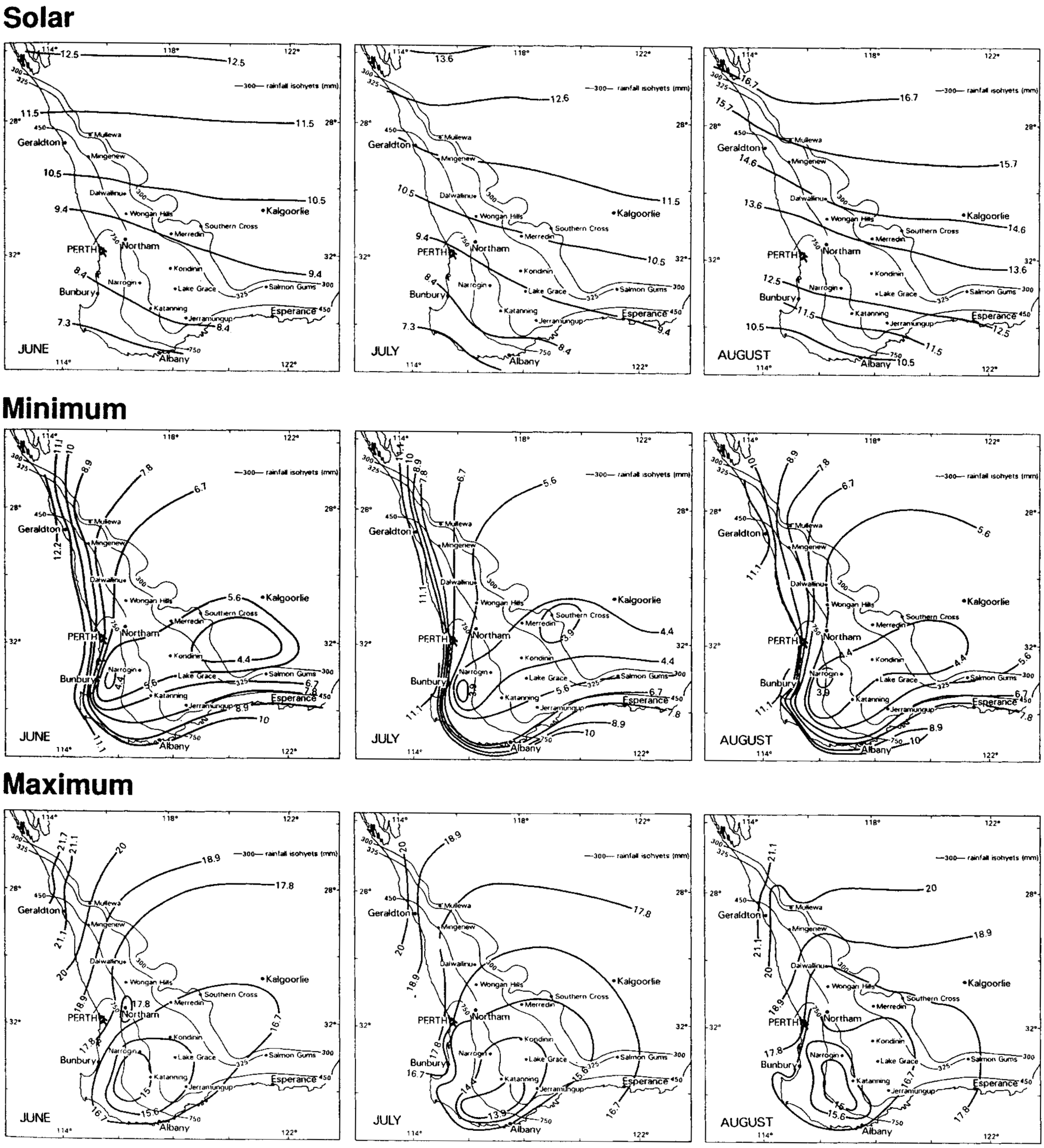
Table 1.1 – Annual growing season (May to October) rainfall for some major centres in the wheatbelt of western Australia.

Locality	Annual (mm)	May to Oct (mm)	May to Oct (%)
Geraldton	370	395	84
Mullewa	337	253	75
Mingenew	414	338	82
Wongan Hills	387	297	77
Bencubbin	319	211	66
York	454	366	81
Merredin	326	231	71
Hyden	334	225	67
Katanning	482	362	75
Salmon Gums	342	209	61
Albany	937	709	76
Esperance Downs	490	334	68

The concentrated winter rainfall pattern means that waterlogging can be severe in winter, nutrients can be readily leached as water penetrates below the root zone, and that recharge of watertables may be difficult to prevent, particularly under shallow rooted annual species.

■ CLIMATE IN RELATION TO AGRICULTURE IN SOUTH-WESTERN AUSTRALIA *(continued)*

Figure 1.5



Mean monthly solar radiation (MJ/m²/day), minimum and maximum temperature (°C) for June, July and August.

■ CLIMATE IN RELATION TO AGRICULTURE IN SOUTH-WESTERN AUSTRALIA *(continued)*

Rainfall has had another indirect, but important, influence on the agriculture of the region - salt. The large amounts of salts stored in the subsoils of the wheatbelt are of maritime origin. The salts have a composition similar to that of sea water. Over much of the wheatbelt between 20 and 40 kg of salt is added to each hectare from rainfall every year.

Without the drainage systems to return this salt to the oceans, it has accumulated in the subsoils and is now causing salinization of parts of the landscape where rising watertables (caused by clearing) bring the saline groundwaters to the surface.

Solar radiation

Solar radiation is the second most important climatic element after rainfall, because it determines the temperature and evaporation regimes which drive plant growth. Figure 1.5 illustrates the pattern of solar radiation received during the winter months of June, July and August. At 8 to 10 megajoules per square metre per day ($MJ/m^2/day$), solar radiation is unlikely to limit crop growth, especially as crop and pasture leaf areas are low in winter.

The solar energy reaching the ground in summer may reach 30 $MJ/m^2/day$ due to the elevation of the sun, the clear atmosphere and cloud-less skies. These are amongst the greatest radiation loads received at the earth's surface and are one reason for the productivity of irrigated summer crops in regions of Mediterranean climates.

Temperature

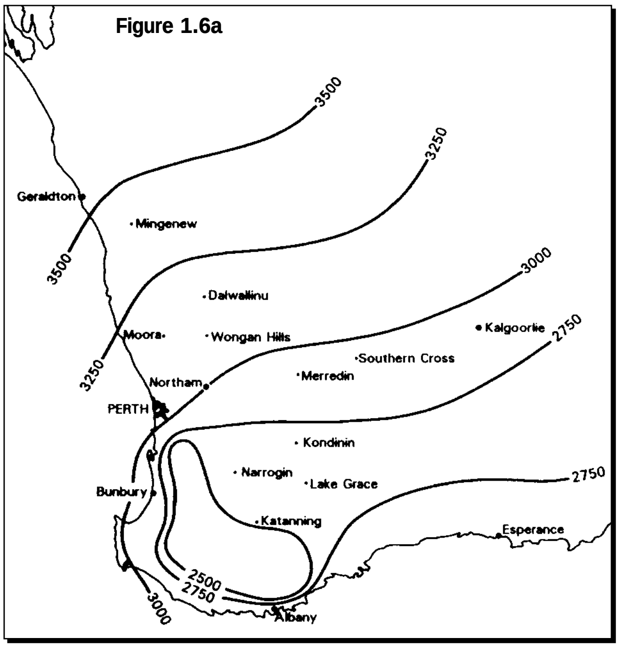
Mean annual temperatures for the wheatbelt follow closely the trends of solar radiation, however, winter temperatures are moderated close to the coast by the Indian and Southern Oceans. Coolest temperatures occur in the southern and eastern wheatbelt (Figure 1.5) where mean temperatures are between 10 and 12°C for the winter months. Minima for the same period are 4 to 5°C, and maxima 14 to 16°C. The optimum temperature for wheat growth is about 25°C.

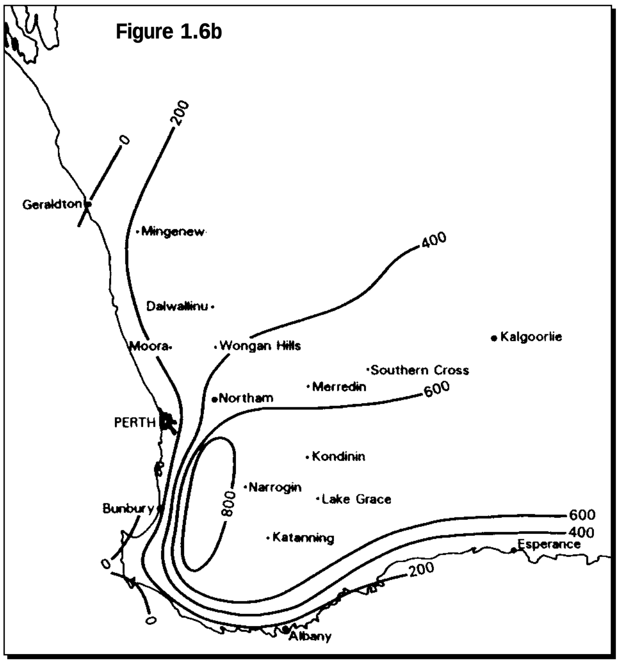
Although mean temperatures indicate the suitability of the environment for crop growth, processes such as leaf growth, tillering and the progress of plant development are often closely related to the *Accumulated* temperature. This is expressed in °C.days (degree days) and is explained in Chapter 3. Basically, it is the sum of the mean temperatures for each day.

Figure 1.6 shows the accumulated temperature or 'growing °C.days' for May to October. Accumulated temperatures are useful for comparing growing environments. From the meteorological tables in the Appendix, it is possible to calculate accumulated temperatures for many other purposes.

Low temperatures can stimulate the development of some wheats. Accumulated temperatures below 10°C can be a measure of the ability of the environment to satisfy a plant's low temperature requirement.

In Western Australia, temperatures are low enough to stimulate most winter wheats to flower but the season is not long enough to allow them to reach their full yield potential.





a. Growing °C days (base 0°C), and b. vernalizing °C days (accumulated temperature below 10°C for April to October).

Synoptic events

During winter, there are several synoptic events (that is, weather occurring over several days) which are of particular importance to agriculture. These are shown in

■ CLIMATE IN RELATION TO AGRICULTURE IN SOUTH-WESTERN AUSTRALIA *(continued)*

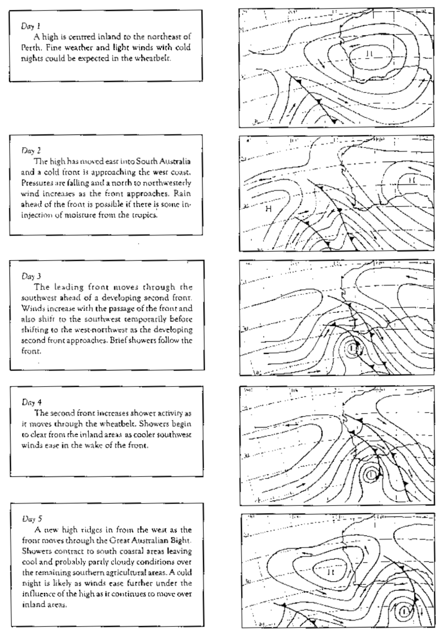


Figure 1.7

Typical series of daily weather charts showing events during the passage of cold fronts.

the series of daily pressure maps in Figure 1.7, illustrating a typical sequence of weather events.

The most obvious is the passage of cold fronts over the southern part of the state during days 3 and 4 of the sequence. As explained previously, this is the main source of rainfall during winter and spring.

Another aspect is the potential for wind erosion. If the sequence of events in Figure 1.7 occurs in late autumn or early winter, the situation on Day 2 could present a risk of wind erosion. Strong northerly winds can be generated as the approaching front increases the pressure gradient between itself and the high to the east. If the land has minimal plant cover from grazing pressure, or from dry seeding, then susceptible soils will suffer wind erosion. Fine particles and nutrients will be lost as dust and larger soil particles can move across paddocks, piling up along fence or tree lines.

In late winter and spring, the last day of the sequence increases the likelihood of frost. The preceding days (days 3 and 4) are likely to have been cloudy, wet and cool or cold. As the new high establishes itself the night will probably be cloud-free and there will be no or light winds. Under these conditions, the land surface will cool rapidly through radiation of thermal energy to space.

The combination of preceding cool days, cold southerly airflow and clear skies can produce low temperatures. Cold air will tend to move downslope and accumulate in the lowest parts of the landscape, often producing frost as water vapour freezes on plant surfaces. In severe cases, water inside plant tissues freezes and bursts the cells.

Frost is an important agricultural risk and is covered in more detail in Chapter 7.

Climatic sub-division of the wheatbelt

The primary sub-division of climate for the south-west of Western Australia is a north-south separation approximately at right angles to the western coast. A second sub-division can be made on the pattern of rainfall isohyets parallel to the coast.

This map (Figure 1.8) is similar to the regional sub-divisions adopted for Agriculture Western Australia's crop variety recommendations.

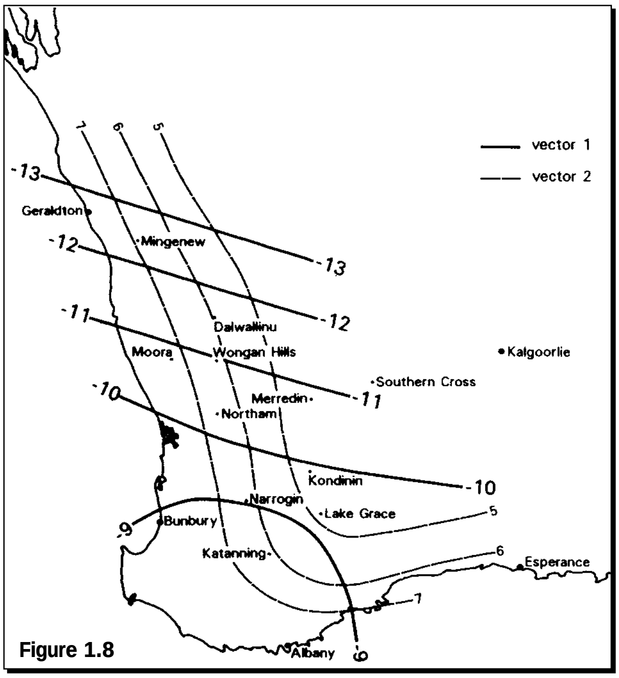


Figure 1.8

A sub-division of the south-east of Western Australia according to climatic features.

Australian climates used for wheat production

It is often assumed that wheat production throughout southern Australia takes place in a relatively similar environment: so that technology and production systems might be readily transferred. This is not the case.

Although the westerlies dominate in the south, the climate of eastern Australia is more complex. Winter rainfall from the westerlies is supplemented by summer rainfall from moist air masses from the Pacific Ocean. Rainfall grades from strongly winter-dominant in the west, through a uniform, all-year-round distribution in Victoria and southern New South Wales, to strongly summer-dominant in the north. The range is illustrated in Figure 1.9.

The Australian wheatbelt can be divided into three regions: a southern winter rainfall region, a northern region of summer-dominant rainfall and a south-eastern region of high (greater than 550mm), and evenly distributed rainfall.

■ GLOBAL CIRCULATIONS AFFECTING WEATHER IN SOUTH-WESTERN AUSTRALIA *(continued)*

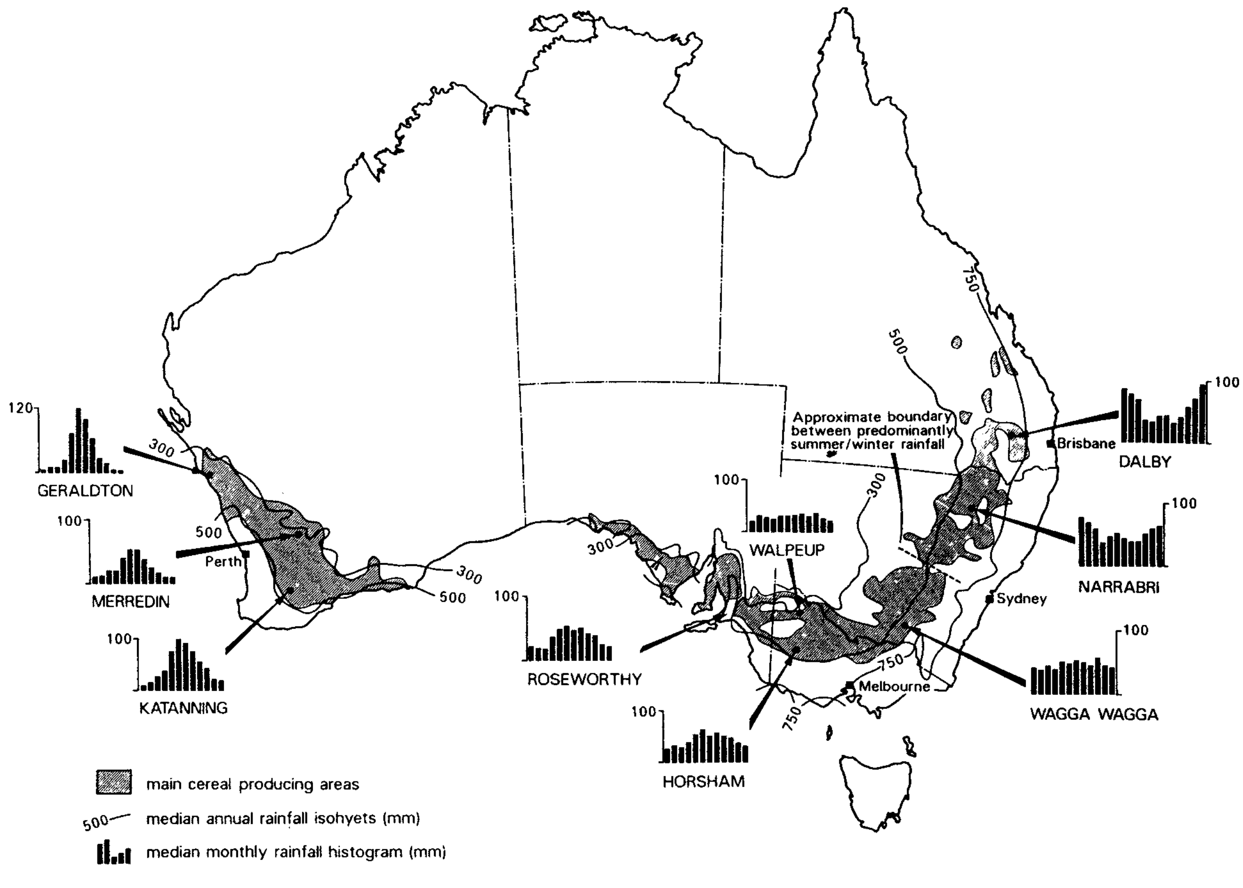
The winter rainfall region produces about 70% of Australia's cereals; and includes Western Australia, South Australia, Victoria and southern New South Wales. The characteristic winter peak is most extreme in the west where Geraldton and Wongan Hills receive 80 to 85% of the annual rainfall in the growing season. More typically, 60 to 70% of rainfall is received in the growing season, (Merredin 66%, Clare 61 per cent, Walpeup 59% and Horsham 58%). Mid-winter temperatures are mild (12 to 15°C day / 5 to 8°C night) and mid-winter radiation levels low (9 to 11 MJ/m^2/day).

The summer rainfall region extends from central New South Wales to Queensland and accounts for about 25% of cereal production. Rainfall is greater and increases in both amount and summer dominance to the north. Dubbo, for example, receives 531mm, with 42 per cent falling in winter, Narrabri 662mm (38%), Dalby 614mm (29%) and Biloela 705mm (19%).

Mid-winter temperatures are higher (15 to 19°C day / 8 to 12°C night) than in the southern region except at high elevation. Radiation frosts after ear emergence may cause severe damage and planting times are adjusted to avoid flowering during the period of greatest risk of frost.

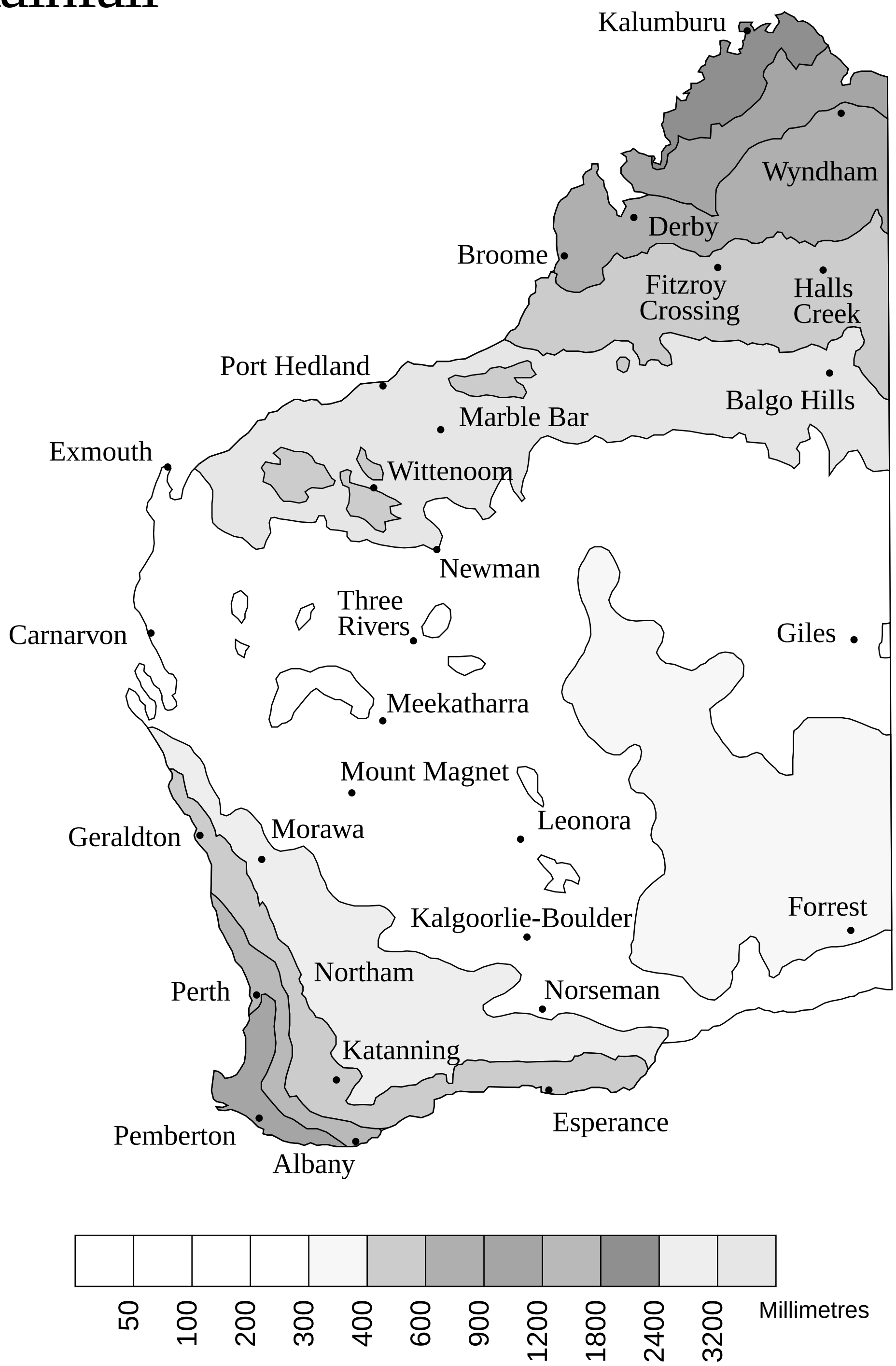
The south-eastern region, which lies to the south and east of the present wheatbelt, is high rainfall (over 550mm) with significant amounts in both summer and winter. This region produces less than 5% of Australia's wheat.

Figure 1.9



Rainfall amount and distribution for the wheatbelt of western, southern and eastern Australia.

Average Annual Rainfall



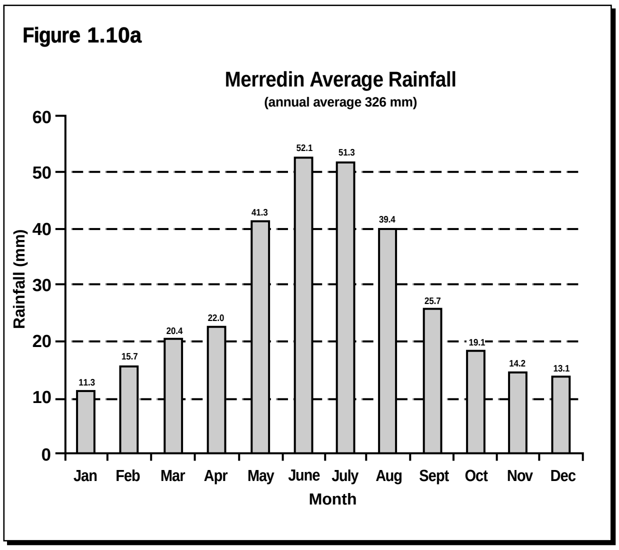
Based on a standard 30-year climatology (1961 to 1990)

CLIMATE VARIABILITY AND SEASONAL FORECASTING

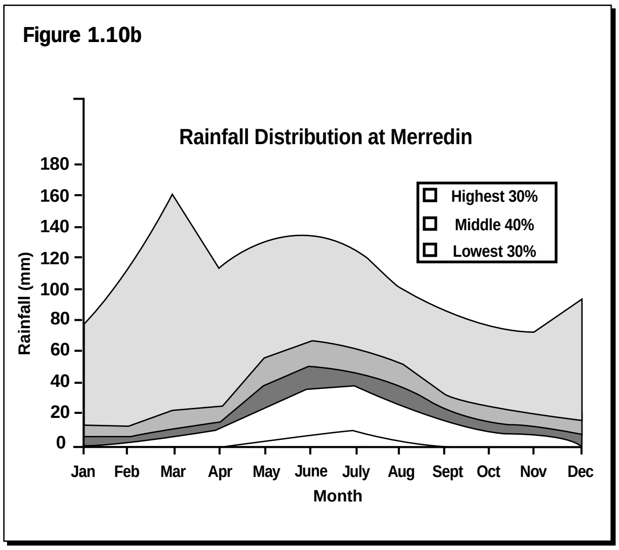
Joe Courtney

Western Australian Regional Office, Bureau of Meteorology

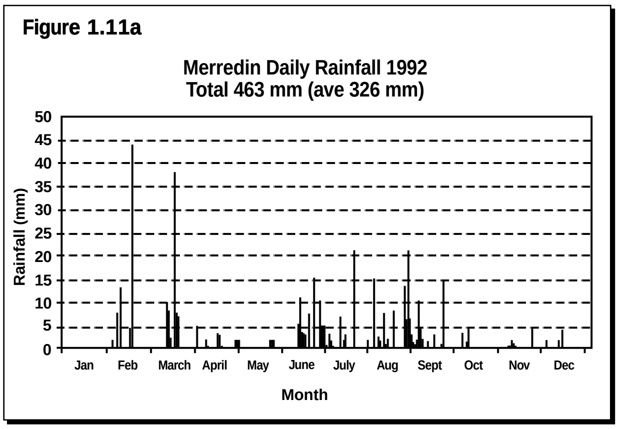
Most people tend to think of averages when talking about the climate of an area. The annual average rainfall map (opposite) shows the geographic distribution of average rainfall and a site's monthly averages (Figure 1.10a) indicate the general distribution during the year. This is a good starting point but sometimes more important is knowing the variability of the climate from one year to the next. The distribution of rainfall in each month can be expressed using deciles or percentiles which show the chance of getting certain amounts of rainfall (Figure 1.10b). For example, at Merredin in July when the median is 48mm, in the driest 30% of July months rainfall is less than 37mm and in the wettest 30% of July months rainfall is at least 59mm. The lowest reading is 9mm and the highest is 127mm.



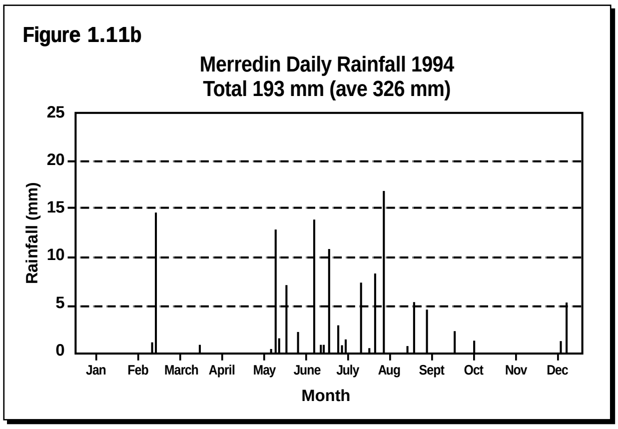
Average annual rainfall at Merredin.



Monthly rainfall distribution at Merredin.



Daily rainfall at Merredin in 1992.



Daily rainfall at Merredin in 1994.

However, this is still looking at rainfall on a monthly basis. The timing and amount of daily rainfall is probably a better guide in determining the characteristics of a season. For example, the years 1992 and 1994 show completely different rainfall patterns and would require different management strategies to optimise property production (Figure 1.11).

Mechanisms that modify the seasons

We are quite familiar with the causes of day to day weather patterns such as the movement of highs, lows and cold fronts. However, trying to explain the variations of the seasons one year to the next has been far more complicated.

While there is still a long way to go, research in the past 20 years has uncovered some of the influences on our seasonal weather patterns. Variations are linked to the three oceans surrounding the continent (Indian, Pacific and Southern). The effects of each of these wax and wane, interacting with each other, making each year different from the last. Three identified effects are known as the El-Nino Southern Oscillation (ENSO) in the Pacific Ocean, the Indian Ocean Dipole, and a recent discovery of yet to be determined significance, the Antarctic Circumpolar Wave in the Southern Ocean. Each involves both the atmosphere and ocean acting together and affecting each

■ CLIMATE VARIABILITY AND SEASONAL FORECASTING *(continued)*

other. These effects, together with others less well known or yet to be discovered, combine to be responsible for producing such a variable climate in Australia.

However, we are still limited in our ability to predict important seasonal features such as the timing of the first significant cold front that is often responsible for the break of season.

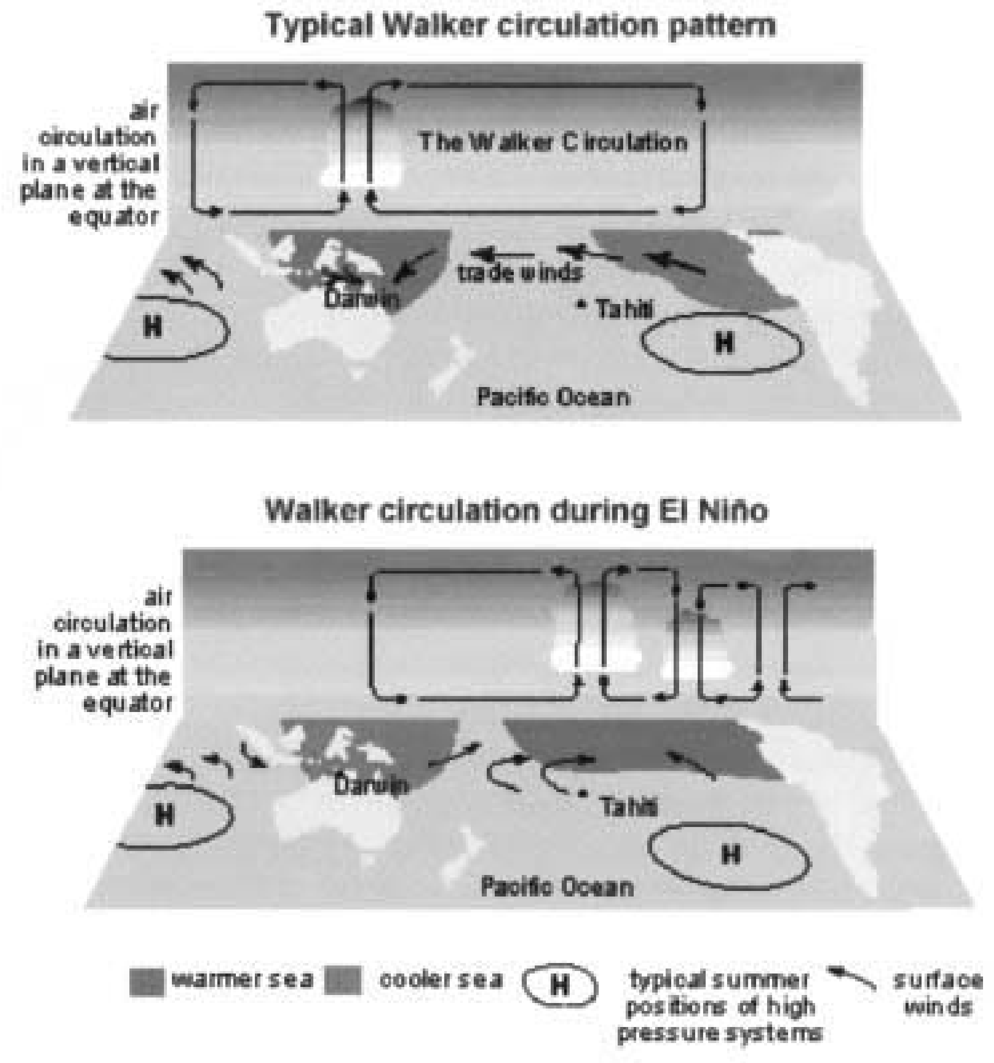
El Nino – Southern Oscillation

El Nino translates from Spanish as 'the boy-child'. Peruvian fisherman originally used the term, a reference to the Christ child, to describe the appearance, around Christmas, of a warm ocean current off the South American coast.

Nowadays, the term El Nino refers to the extensive warming of the central and eastern Pacific that leads to a major shift in weather patterns across the Pacific (Figure 1.12). El Nino events are associated with an increased probability of drier conditions particularly in eastern Australia.

Of the three factors listed above, ENSO is the most studied, best known and the most important feature for Australia's rainfall patterns. El Nino affects many parts of the globe, and is particularly significant for northern and eastern Australia. Its focus is the tropical Pacific Ocean where big changes can occur that involve both the atmosphere and the ocean interacting and affecting each other. These changes oscillate irregularly between two main states: El Nino and La Nina. These extreme events last for about 12 to 18 months with autumn often being the

Figure 1.12



Schematic diagram showing the major ENSO patterns.

■ CLIMATE VARIABILITY AND SEASONAL FORECASTING *(continued)*

transition period, although the 1990s has witnessed an above average number of El Ninos, some in succession.

Changes to the atmosphere and ocean circulation during El Nino events include:

- Warmer than normal ocean temperatures across the central and eastern tropical Pacific Ocean.
- Increased convection or cloudiness in the central tropical Pacific Ocean - the focus of convection migrates from the Australian/Indonesian region eastward towards the central tropical Pacific Ocean.
- Weaker than normal (easterly) trade winds.
- Low (negative) values of the SOI (Southern Oscillation Index).

The term La Nina refers to the extensive cooling of the central and eastern Pacific Ocean (note: the term 'La Nina' has only recently become the conventional meteorological label for the opposite of El Nino). In Australia (particularly eastern Australia), La Nina events are associated with increased probability of wetter conditions.

Changes to the atmosphere and ocean circulation during La Nina events include:

- Cooler than normal ocean temperatures across the central and eastern tropical Pacific Ocean.
- Increased convection or cloudiness over tropical Australia, Papua New Guinea, and Indonesia.
- Stronger than normal (easterly) trade winds across the Pacific Ocean (but not necessarily in the Australian region).
- High (positive) values of the SOI.

ENSO is monitored in a number of ways. A simple but effective measure is the SOI. The SOI is calculated from the monthly or seasonal fluctuations in the pressure difference between Tahiti and Darwin. Sustained negative values of the SOI often indicate El Nino episodes, while positive values indicate La Nina episodes (Figure 1.12), also for more information see **http://www.bom.gov.au/climate/glossary/elnino.shtml.**

ENSO and South-west WA

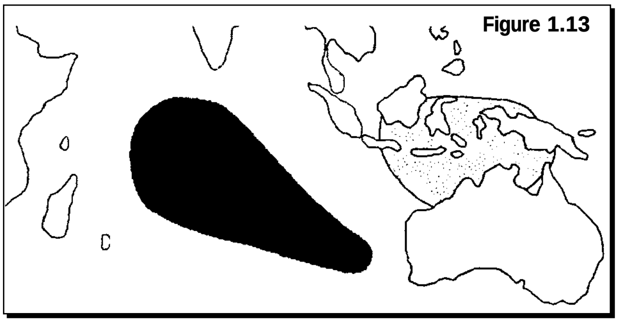
Correlations of ENSO with rainfall in the wheatbelt are much less than those in the eastern states. In El Nino years there is a slight bias towards drier conditions at some stages of the year, while in La Nina years there is a slight bias to wetter conditions. It must be noted that the correlations between rainfall and ENSO vary depending on the way in which the signals are used. For example, sometimes the trend in SOI is more useful than the actual values of the SOI.

Indian Ocean Dipole

A dipole pattern of sea-surface temperatures (SST) in the Indian Ocean has been related to bands of cloud that sweep across the continent from north-west to south-east, known as north-west cloudbands. These cloudbands are important rainfall mechanisms form April to August through the Gascoyne, Murchison and northern agricultural areas in particular, and are often associated with the break of the season for the northern and central wheatbelt.

When there is warm water north of Australia and a relatively colder region in the central Indian Ocean west of the continent (see figure 1.13), the resulting stronger than normal sea surface temperature gradient assists in producing the moisture-laden north-westerly flow over Australia enhancing the occurrence of north-west cloud bands. The reverse pattern of relatively cold water in the central Indian Ocean is associated with reduced rainfall by suppressing north-west cloudbands. Research at CSIRO is investigating links with the SST anomalies and the depth of warm water near the surface, the sea level height, the transport of water around the Indian Ocean and also the links with ocean patterns in the Pacific.

Figure 1.13



Indian Ocean dipole.

The Antarctic Circumpolar Wave

This phenomenon has only recently been discovered and while its impact appears to be strongest in southern Australia, it is not yet known how significant it is for Western Australia. The southern ocean contains a large current which flows continuously around the Southern hemisphere at about 10cm per second, carrying most of the water with it. It takes about eight or nine years for this current to transport water completely around the globe.

Carried along with this current are two large regions of relatively warm water, thousands of kilometres across and 1km deep, alternating with two equally large regions of relatively cold water. This pattern is called the Antarctic Circumpolar Wave (Figure 1.13) and, like ENSO, appears to be due to interactions between the ocean and the atmosphere. The wave is also associated with pressure and wind patterns and the extent of sea-ice from Antarctica.

When the warm region is present south of Australia, winds carry slightly more moisture than usual causing winters to be slightly wetter and warmer than normal. Conversely, cold water south of Australia brings cooler and drier conditions to southern Australia. Being such a recent discovery it is difficult to assess the significance of this feature and how it affects rainfall in south-west Western Australia.

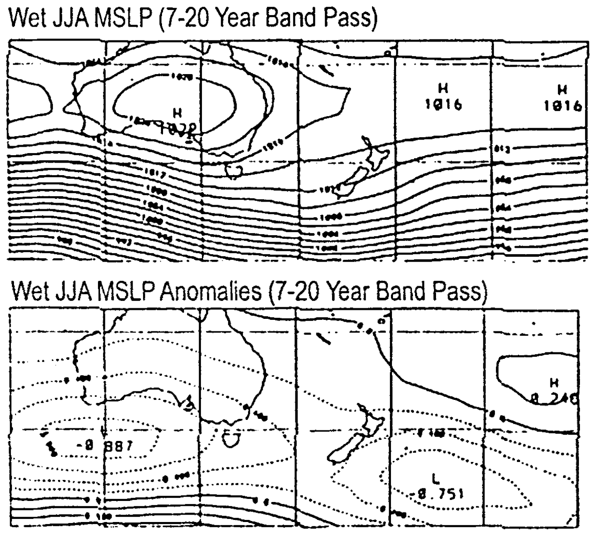
■ CLIMATE VARIABILITY AND SEASONAL FORECASTING

(continued)

Wet and dry years

A CSIRO study has compared pressure patterns between the wet and dry winters in Western Australia (Allan and Haylock, 1993). By compositing the pressure fields they produced pressure fields and anomaly fields for both the dry and wet years (see Figures 1.14a and 1.14b). This showed that in dry years, pressures were higher around Australia particularly to the immediate south of the continent. In the wet years, pressures were lower around Australia (particularly south of Western Australia) suggesting an increase in cold front activity.

Figure 1.14a



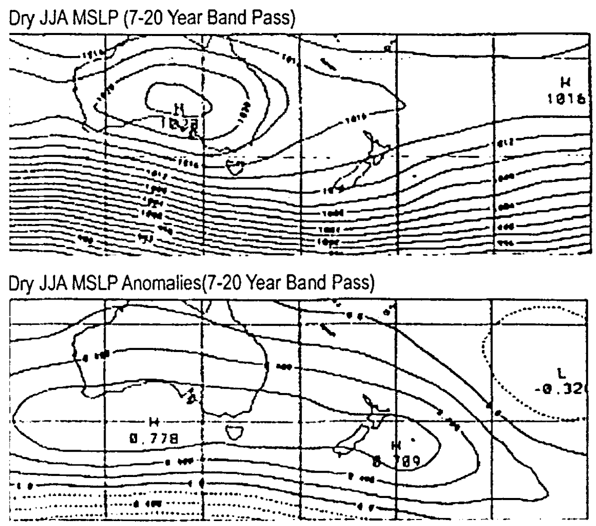
Explaining the variations – some examples

Let's return to the years 1992 (wet) and 1994 (dry). Although El Nino events tend to last for only 12 to 18 months there was an extended period of El Nino conditions between 1991 and 1994. However, there were noticeable differences between the two years in terms of global patterns.

By early 1992 an El Nino event had reached full maturity and it began to weaken in autumn. Nevertheless, the average SOI for January to April was - 19.4, an exceptionally low value. This weakening coincided with a strong Indian Ocean dipole signal associated with considerable north-west cloudband activity. Well above average rainfall occurred in autumn and winter through much of southern Western Australia with some record totals in the eastern wheatbelt and Goldfields area.

In 1994, the SOI decreased from near zero values in January and February to be strongly negative for the remainder of the year signalling the re-emergence of El Nino. In addition, a reverse Indian Ocean dipole with relatively very cold water off Indonesia led to a suppression of north-west cloudbands. Conditions in the wheatbelt were very dry until the end of May and yearly totals were below average. While we do not fully understand the mechanisms that cause these seasonal rainfall variations, it is clear that the oceans have a major role to play.

Figure 1.14b



What does it mean for seasonal forecasts?

How these mechanisms relate to each other and the combined affects on our rainfall are the basis of research to improve seasonal forecasting. Until quite recently the Bureau of Meteorology's seasonal outlooks were based entirely on ENSO. A more sophisticated scheme using ocean patterns in both the Pacific and Indian Oceans is now operational. These are three-month outlooks giving the probability of receiving below average, average and above average rainfall. The accuracy varies during the year, and with each year, according to variations in the oceanic system. A summary of the outlook is available on the internet (http://www.bom.gov.au/climate/ahead/rain_ahead.shtml, by Weather by fax (1902 935 251) or through some media outlets.

The Indian Ocean Climate Initiative (IOCI) is a Western Australian initiated partnership to foster research into climate variability and development in seasonal forecasting. The results from this effort are likely to improve the understanding of seasonal mechanisms and hopefully lead to improved forecast skill on a seasonal basis.

■ CLIMATE VARIABILITY AND SEASONAL FORECASTING

(continued)

Climate trends in rainfall and temperature

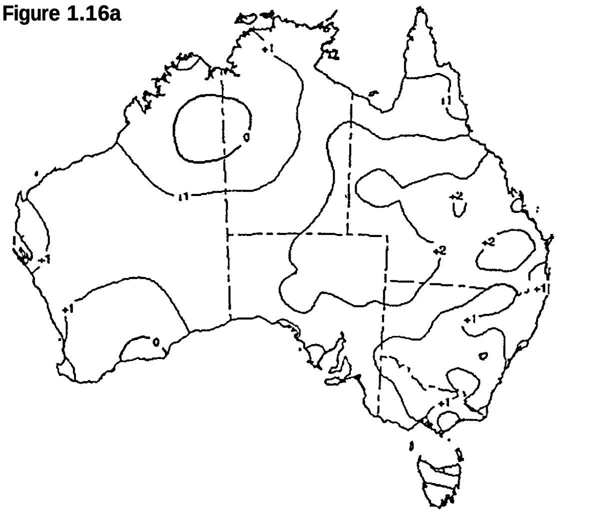
Apart from year to year variability, the issue of long-term changes in rainfall and temperature patterns is of great importance, and concerns over global warming and its impacts have attracted great interest over the past decade or so.

Rainfall has declined in the south-west over the course of this century particularly in the far south-west since the 1940s (Figure 1.15). The trend in May to October rainfall closely matches the annual rainfall trend, although the November to April trend is weaker and more varied. Rainfall patterns in the eastern wheatbelt show less obvious trends.

Trying to understand the mechanisms of these changes and ultimately to be able to predict future rainfall are aims of a major research study. The current downward trend in winter rainfall over the south-west may be due to a general warming of a wide area of the Indian Ocean over the last few decades and variations in the large-scale atmospheric circulation across southern Australia since 1971. This trend may be regarded as a part of the natural variability of the climate system. This is supported by the fact that annual rainfall increased from the earliest rainfall records last century until the early to mid part of the 20th century.

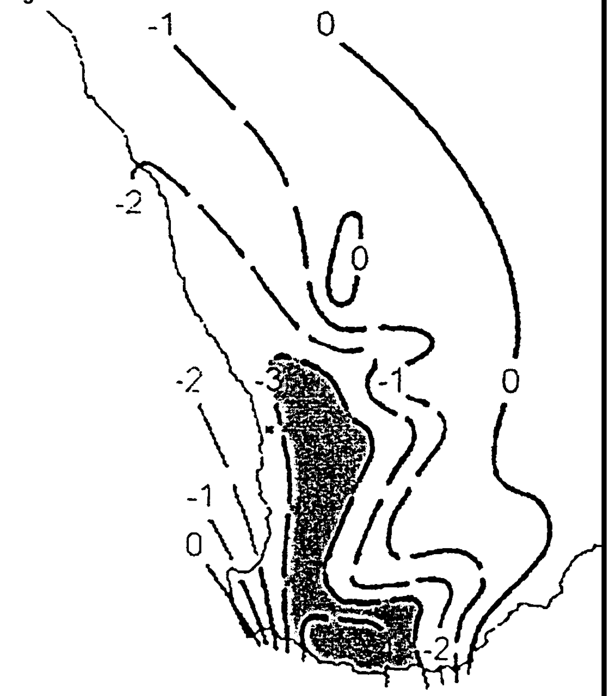
Consistent with trends elsewhere in Australia, average maximum and minimum temperatures have increased in Western Australia since instrumental records began (Figures 1.16a and 1.16b). There are many difficulties associated with comparing historical temperatures including change of instrument type, changes in observing practices and sites, and changes in the environment surrounding the instrument (particularly in urban areas). Nevertheless, with these issues taken into account research into observations of temperature indicate a definite long-term increase.

Figure 1.16a



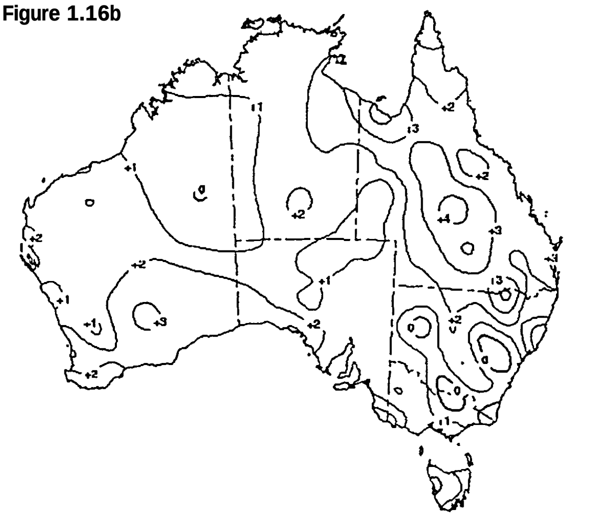
Trend in annual maximum temperature (1959-94).

Figure 1.15



Trend in annual rainfall 1910-1989 (%/decade).

Figure 1.16b



Trend in annual minimum temperature (1950-94).

■ CALCULATING RAINFALL PROBABILITIES FROM DECILES

John Cramb
Western Australian Regional Office,
Bureau of Meteorology

Deciles

Deciles are a method of describing rainfall probabilities for a month, group of months or a year. They are therefore useful for comparing recent rainfall with the average. Because rainfall and crop yield are closely related, they may therefore give some clue to likely yields at the end of season.

Deciles are obtained by dividing the historical rainfall into tenths. The deciles obtained range from 1 to 9 and each has a corresponding rainfall total expressed in millimetres. For example if a monthly total of 65mm has a decile rating of 3 - less than 65mm will be received in 3 years out of ten, and greater than 65mm in seven years out of ten.

Deciles can be summarized as follows:

- ***Decile 9*** 9 in 10 seasons receive less rainfall (or only one season in 10 receives more)
- ***Decile 8***
- ***Decile 7***
- ***Decile 6***
- ***Decile 5*** 5 in 10 seasons receive less than this amount and 5 in 10 more.
- ***Decile 4***
- ***Decile 3***
- ***Decile 2***
- ***Decile 1*** Only 1 in 10 seasons receives less than this amount, 9 in 10 seasons receive more.

Deciles are specific to the location where the rainfall was recorded. Decile values for monthly and annual rainfall totals have been calculated by the Bureau of Meteorology for many centres in Western Australia and are freely available. As an example, Table 1.2 gives the monthly and annual decile rainfalls for Merredin.

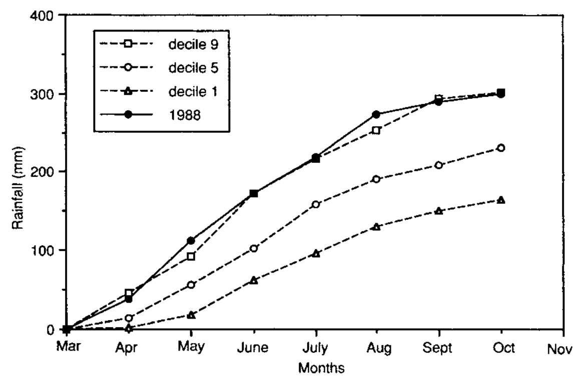
For the annual totals for Merredin, the values opposite decile 9 indicate that only one year in ten will have an annual rainfall greater than 410mm, whilst nine years in ten will have 216mm (decile 1). Note that decile 5 (301mm), the value for which half of all years will be above and half below, is very close to the long term average of 309mm.

The same can be done to the monthly rainfalls. For example, June rainfall will be less than 19mm in only one year in ten.

Using deciles to track seasonal conditions

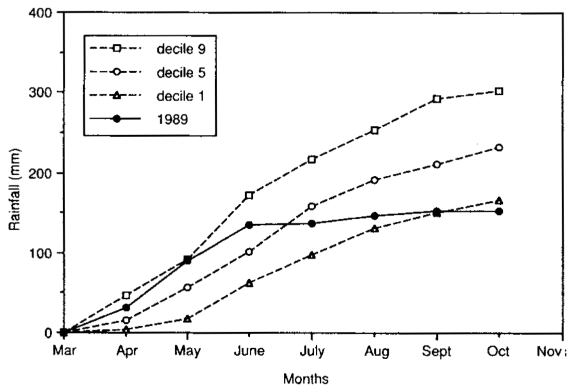
Deciles for the total rainfall received in two, three, or more consecutive months can be calculated and the growing season conditions can be tracked. Starting in April, compare the rainfall received for the month with the decile 9, decile 5 and decile 1 values. Then at the end of May, calculate the total rainfall received for April and May, and compare this with the decile values for the two months combined.

Figure 1.17a **Merredin 1988**



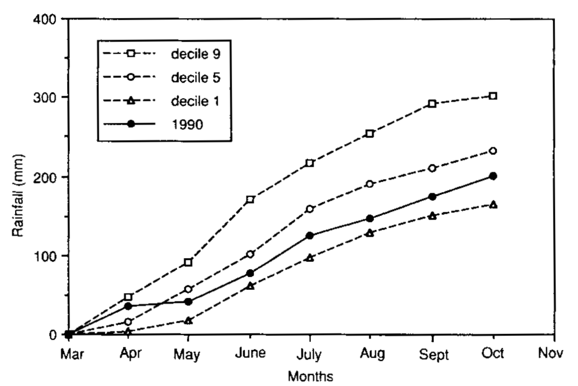
April to October rainfall and cumulative decile rainfall charts for Merredin for 1988

Figure 1.17b **Merredin 1989**



April to October rainfall and cumulative decile rainfall charts for Merredin for 1989.

Figure 1.17c **Merredin 1990**



April to October rainfall and cumulative decile rainfall charts for Merredin for 1990.

■ CALCULATING RAINFALL PROBABILITIES FROM DECILES *(continued)*

In the same way at the end of June, compare the total rainfall for the three months with the appropriate deciles for the three month period; and so on to the end of the season.

The results of this analysis are most easily understood by drawing the cumulative rainfall at the end of each month on a graph with the decile values. Figure 1.17 shows the cumulative rainfall at Merredin in 1988 (a very good season), 1989 and 1990 from the end of April to the end of October. The decile 1, decile 5 and decile 9 rainfall values are also shown.

For 1989, the season was well above average at the end of May and June, but then deteriorated to have below average seasonal rainfall to the end of October. For 1990, seasonal conditions were below average.

Deciles can also be used to update the probabilities for total seasonal rainfall, and since this is closely related to grain yield, give some clue to the yield prospects for the season.

If the season is going to be good, with above average rainfall, there are likely to be good responses to additional nitrogenous fertilizer, copper or molybdenum sprays may be required on high biomass crops and there are likely to be good yield responses to herbicides.

On the other hand, if the season is going to be below average, the chance of profitable responses to additional inputs is less or may even be negative.

Making such forecasts, which look ahead to the end of the season, is more complex than simply tracking the progress of the season, but such services are potentially of great value.

■ LANDFORMS AND SOILS OF SOUTH-WESTERN AUSTRALIA

Peter Tille
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General soil characteristics

The soils of south-western Australia have a reputation for being sandy with inherent low fertility. Many major and minor elements such as N, P, K, S, Cu, Zn, Mn and Mo are deficient for plant growth. This is largely due to the age of the soils and their high degree of weathering, there being a small proportion of freshly renewed soils in comparison with most other wheat growing regions of the world. The weathering has also led to a predominance of sandy textured topsoils consisting of highly resistant quartz grains. Silty materials are rare and the clayey subsoils are dominated by kaolinitic minerals. The widespread occurrence of iron and aluminium rich laterite is another characteristic of the soils and landscape. While the above generalisations are broadly true, there are wide variations in soil types and fertility.

History and geology

The distinctive landforms of south-western Australia and the soils associated with them reflect their geological history. Much of the south-west occurs on a geologically stable area, known as the Yilgarn Craton, which consists of acid granitic rocks and is one of the oldest remaining portions of the earth's surface (over 2,500 million years old). The western boundary of the Yilgarn Craton is the Darling Fault which extends from Mullewa and Three Springs to Donnybrook and Nannup. This fault is one of the largest lineaments on the Earth's surface being 1,000 km long with a current topographical expression of up to 200 m along the Darling Scarp.

Granitic geology occurs along the south coast and at Margaret River and Northampton. While these rocks are younger the those of the Yilgarn Craton, they are still over 1,000 million years old. All of these areas have been worn down by erosion for several hundred million years. As a result of the old age of the landscape there are no major mountain ranges, relief is low and subdued, and drainage often sluggish.

To the west of the Darling Scarp, the underlying geology consists mainly of sedimentary rocks, such as sandstones and siltstones. Along the coast between Geraldton and Busselton these are overlain by the more recent sediments of the Swan Coastal Plain. Sedimentary rocks are also found along the South Coast overlying the granitic basement. In some places the sedimentary rocks have given rise to prominent landscape features such as the flat topped mesa of the Moresby Range near Geraldton. The Stirling and Barren Ranges on the South Coast have formed on metamorphosed sediments.

Much of the south-west is overlain by a mantle of deeply weathered material dating back 50 million years or more. This weathered surface is commonly 30-50 m deep, laterite is a prominent feature which has formed over granitic and sedimentary rocks. The lateritic profile is characterised by an accumulation of iron and aluminium near the surface. It typically consists of a surface layer of sand and ironstone gravel overlying an iron indurated crust of cemented gravel (duricrust). The duricrust is typically underlain by a heavily mottled clay (mottled zone) grading into a pale coloured clay from which most of the iron has been removed (pallid zone). Below this is a partially weathered material (saprolite) which typically consists of a gritty material retaining the fabric of the underlying rock.

The extent of dissection is controlled by earth movements mainly around the south-western margin of the otherwise stable Yilgarn Block. Upwarping to form the Darling Range, and a downward sag along the zone of seismic activity running through Brookton, Beverley, Northam and beyond has led to renewed down-cutting by the marginal rivers and streams.

The process has extended inland to truncate the ancient drainage lines represented by the salt lake chains to a limit shown on Figure 1.18 as the Meckering Line. Some geologists believe that the salt lake chains of the interior represent ancient river systems which flowed before the super-continent of Gondwanaland began to break up and the major land masses of the world drifted apart.

Upstream of the Meckering Line lies the Zone of Ancient Drainage where lateritic profiles are widespread on the extensive uplands between the wide, flat floored trunk valleys with low gradients.

Downstream is the Zone of Rejuvenated Drainage with more frequent dissection, closer more incised stream system, and the divides are smaller. They are again crowned with laterite and often defined by prominent breakaways. However, the pallid zone clays are still present on the relatively steep valley side slopes beneath a generally shallow sandy veneer.

In the higher rainfall areas lateritic profile is absent only where slopes are steeper and topographic relief greater. Erosional and depositional processes acting over a very long time have dissected the lateritic landscape to expose limited areas of fresh rock on which younger and more fertile soils have formed. In the Darling Range, despite its well developed stream system, and generally hilly topography, lateritic materials mantle almost the whole landscape, often in the form of duricrust. Perhaps due to the high rainfall, weathering is even more extreme, so that oxides of aluminium are concentrated in relation to other constituents to form bauxitic laterites in parts of the landscape.

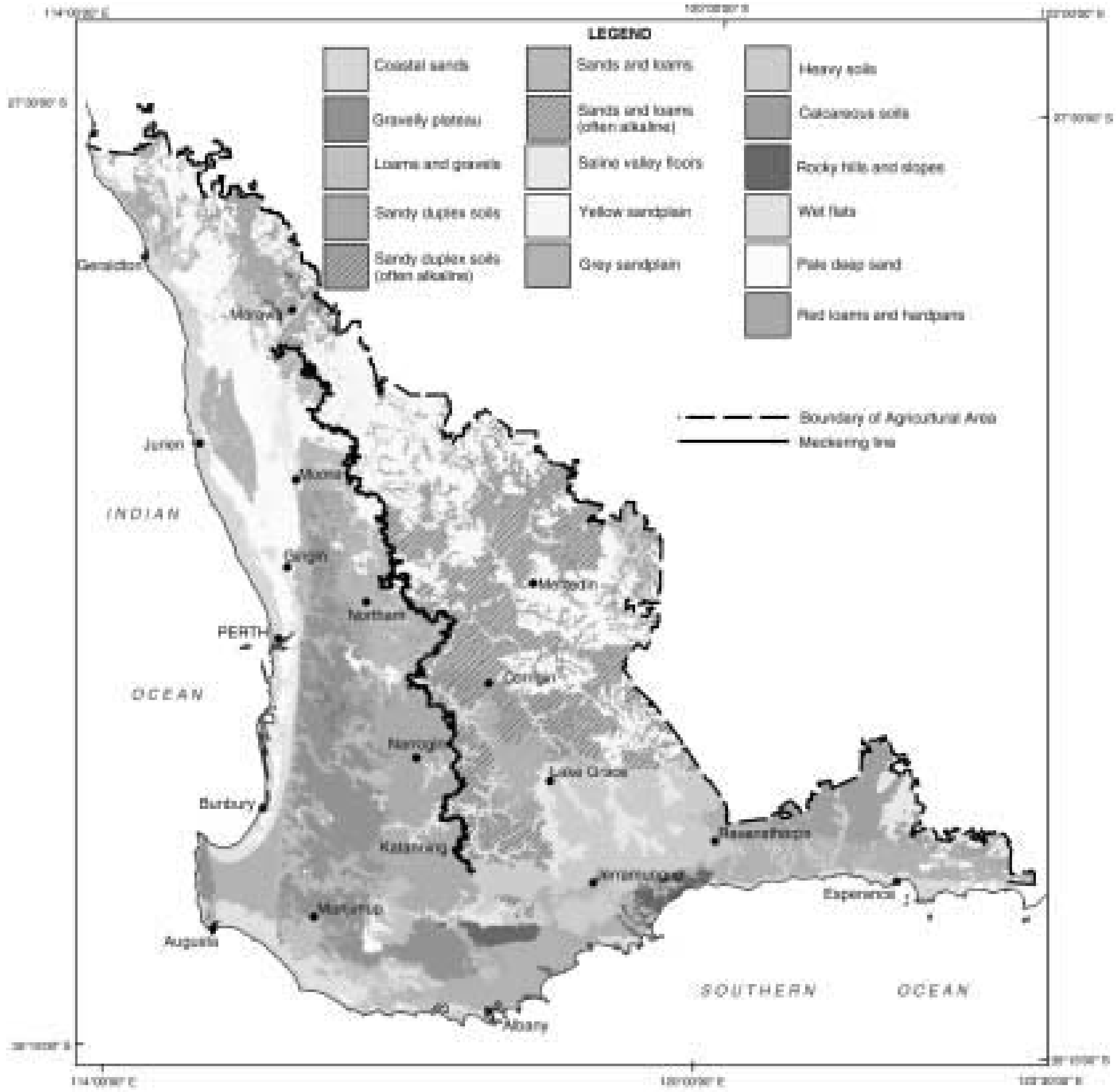
Salt in the landscape

The deeply weathered profile in south-western Australia contains large quantities of soluble salts, mainly sodium chloride. In the wheat growing areas the salt stored

■ LANDFORMS AND SOILS OF SOUTH-WESTERN AUSTRALIA

(continued)

Figure 1.18



The soils of south-western Australia.

in the landscape may amount to a million or more kilograms per hectare, most of it in the deep subsoils and saline watertables.

The salts originate in the ocean, and are carried inland in dilute concentration in the rainfall. While the water is lost from the soils by evaporation and transpiration, there is no escape for the salts, which are retained. Even the large amounts present would have taken only about 10,000 years to accumulate at present rates of accession, a very short time in comparison with the long period of leaching which must have preceded it.

Soils of the wheat growing areas

The major soil types of Western Australia have been placed into 56 groups. These groups have been further amalgamated into 12 supergroups. The supergroups are defined using three primary criteria:

- the texture profile
- the presence and nature of coarse fragments
- the water regime

The soil groups are further divided by the following secondary and tertiary criteria:

- the presence of carbonates
- topsoil colour
- horizon or profile depth
- pH (acidity or alkalinity)
- soil stricture

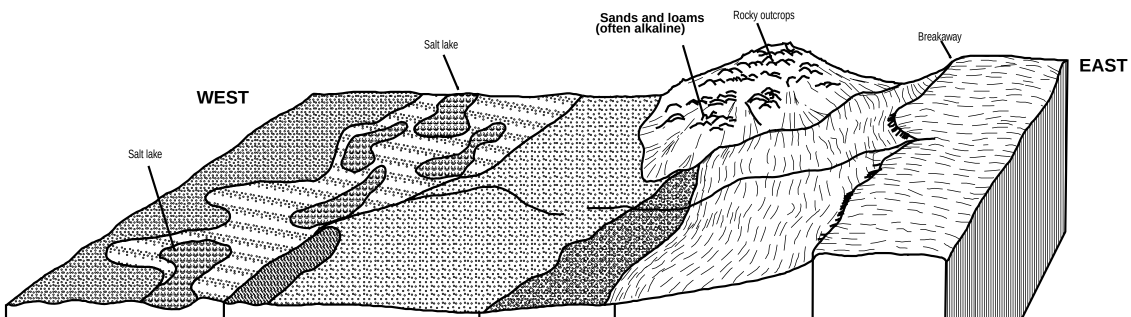
Figure 1.18 shows the distribution of these soils. This mapping is based on the detailed (mapping scales ranging from 1:50,000 to 1:250,000) soil-landscape mapping of the agricultural area of Western Australia. Contact the Natural Resources Assessment Group of Agriculture Western Australia for more details.

The soil types and associated natural vegetation of the wheat growing areas are shown in Figures 1.19 and 1.20.

■ LANDFORMS AND SOILS OF SOUTH-WESTERN AUSTRALIA

(continued)

Figure 1.19



SOIL-LANDSCAPE GROUPING	**Saline valley floor**	**Calcareous soils**	**Heavy soils**	**Sands and loams (often alkaline)** or **Sandy duplex soils (often alkaline)**	**Yellow sandplain** or **Grey sandplain**
MAJOR SOIL GROUPS	Alkaline grey deep sandy duplex, Alkaline grey shallow sandy duplex, Calcareous loamy earths, Saline wet soils, Salt lake soils, Loamy duplex soils	Calcareous loamy earths, Alkaline grey shallow loamy duplex, Alkaline grey shallow sandy duplex, Alkaline red shallow loamy duplex	Grey shallow sandy duplex (often alkaline), Grey shallow loam duplex (often alkaline), Grey non-cracking clay, Heavy cracking clay	Grey deep sandy duplex (often alkaline), Grey shallow sandy duplex (often alkaline), Loamy earths, Sandy earths. Grey deep sandy duplex (often alkaline), Grey shallow sandy duplex (often alkaline), Duplex sandy gravels, shallow gravels	Yellow sandy earths, Acid yellow sandy earths, Yellow deep sands, Gravels Gravelly pale dep sands, Grey deep sandy duplex, Pale deep sands, Duplex sandy gravels
VEGETATION	Salmon Gum, Gimlet, Morrel, Bluebush, Saltbush, Melalueca, Samphire, Barley Grass, Bare ground	Morrel, Salmon Gum, York Gum, Wandoo, Gimlet	Mallee Species, Moort, Yate, Salmon Gum	Salmon Gum, Wandoo, Mallee, Gimlet Wandoo, Salmon Gum, York Gum, Jam, Sheoak	Banksia, Sandplain pear, Tammar, Wodjil, Sanplain Mallee, Christmas Tree, Flame Grevillia

Adapted from: Lantzke and Fulton "Land Resources of the Northam Region" Land Resources Series No. 11, Agriculture Western Australia

Soil types of the eastern wheatbelt and their associated vegetation.

Detailed descriptions of selected soil types are given in the Appendices.

Figure 1.19 represents a cross section of a typical wheatbelt valley inland of the Meckering Line. Modification of the old landscape by natural erosion and deposition is relatively minor, but nevertheless has had an important impact on the soil pattern.

The lateritic profile is best preserved on the upland, but sands tend to accumulate in the depressions as yellow sandy earths, leaving ironstone gravelly soils on the higher areas.

On steeper valley side slopes stripping may expose mottled or pallid zones clays upslope with accumulations of sand downslope to give extensive areas of sandy duplex soils and loamy duplex soils with yellow or pale subsoils.

Where fresh bedrock outcrops or is close to the surface it provides a source of relatively unweathered material which gives rise to naturally more fertile soils, often red loamy earths. These soils may be developed from the bedrock in situ or on extensive water laid deposits derived from it to form the ‘heavy land’ of the broad wheatbelt valleys.

Figure 1.19 shows the typical situation in which the deeply weathered pallid zones lie beneath the valley floor, carrying saline water tables where the salt concentration my be several times that of sea water.

The salt lakes, when dry, are the source of wind blown deposits lying generally along the south-eastern lake shores. Near the lakes they are in dune-like form, often rich in gypsum, sometimes suitable for commercial exploitation. Further out, layers of silty, calcareous and saline loams give rise to the calcareous loamy earths (the so-called ‘snuffy morrell’ soils).

Figure 1.20 shows a valley cross section downstream of the Meckering Line. The soil pattern is essentially the same, but slopes are steeper, valleys more sharply incised, and salt lakes absent. Upland areas with sand thins out and the clays approach the surface soaks or swamps with fresh or brackish water appear, often developing after clearing upslope.

Soils and cereal growing

Cereal growing in south-western Australia presents a variety of management problems arising directly from the inherent properties of the soils.

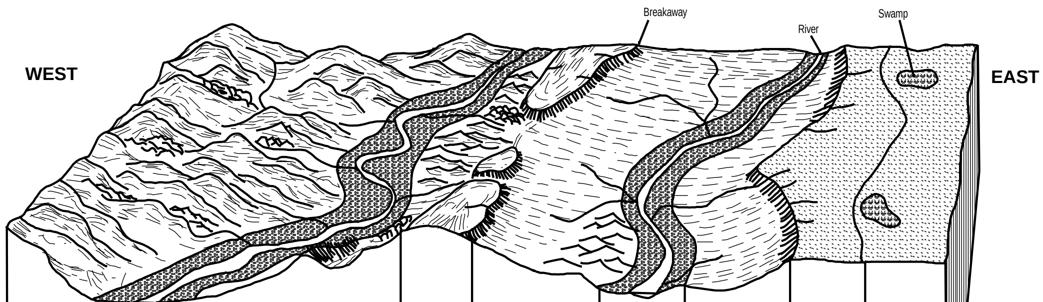
The sandy surface soils are extremely deficient in major and minor nutrient elements. The low clay content means they have a low capacity for retention of most applied nutrients, while the presence of iron oxides leads to fixation and unavailability of applied phosphate.

Resistance to chemical change, known as buffering capacity, is low, so that acidity of surface soils is readily induced by fertilisation.

■ LANDFORMS AND SOILS OF SOUTH-WESTERN AUSTRALIA

(continued)

Figure 1.20



SOIL-LANDSCAPE GROUPING	**Sands and loams**	**Grey sandplain**	**Sandy duplex soils**	**Saline valley floors**	**Sandy duplex soils**	**Grey sandplain**	**Pale deep sands**
MAJOR SOIL GROUPS	Grey deep sandy duplex, Red deep sandy duplex, Grey shallow sandy duplex, Red shallow sandy duplex, Red deep loamy duplex, Red loamy earth	Gravelly pale deep sands, Grey deep sandy duplex, Pale deep sands, Duplex sandy gravels	Grey deep sandy duplex, Grey shallow sandy duplex, Duplex sandy gravels, Deep sandy gravels	Grey deep sandy duplex (often alkaline), Grey shallow sandy duplex (often alkaline), Saline wet soils, Loamy duplex soils	Grey deep sandy duplex, Grey shallow sandy duplex, Duplex sandy gravels, Deep sandy gravels	Gravelly pale deep sands, Grey deep sandy duplex, Pale deep sands, Duplex sandy gravels	Pale deep sands, Gravelly pale deep sands, Grey deep sandy duplex, Duplex sandy gravels, Wet soils
VEGETATION	York Gum, Jam, Sheoak, Salmon Gum, Wandoo, Flooded Gum	Sandplain Pear, Banksia, Tammar, Ti-tree, Christmas Tree, Wandoo	Wandoo, Mallet, Jam, Tammar, Salmon Gum, Sheoak	Wandoo, York Gum, Jam, Salmon Gum, Sheoak	Wandoo, Mallet, Jam, Tammar, Salmon Gum, Sheoak	Sandplain Pear, Banksia, Tammar, Ti-tree, Christmas Tree, Wandoo	Banksia, Christmas Tree, Wandoo, Blackboy, Ti-tree, Rushes

Adapted from: Lantzke and Fulton "Land Resources of the Northam Region" Land Resources Series No. 11, Agriculture Western Australia

Soil types and associated vegetation west of the Meckering Line.

Some deep sands and sandy earths, particularly the acid yellow sandy earths, have naturally acid subsoils which tend to restrict root development.

The water holding capacity of sandy soils is low, so that although the soil water is readily available to plants, it can readily escape below the root zone, contributing to salinisation problems downslope.

Soil organic matter is low and readily lost under warm conditions, leading to poor soil structure and risk of wind erosion.

Kaolinitic clays and oxides of iron and aluminium, common in lateritic materials, have a relatively low capacity to adsorb and retain nutrients, so that the more soluble nutrients such as nitrogen, sulphur and potassium can leach readily.

The tendency of the clays to disperse in water is accentuated by the presence of the sodium ion, leading to structural deterioration, increased run-off and waterlogging downslope.

Management for sustainable production will therefore always be difficult because of the particular characteristics of the soil resource. Advances are likely to come from progressive adaptation of farming systems to soil and climatic conditions.

References

Allan, R.J. and Haylock, M.R., 1993. Circulation features associated with the winter rainfall decrease in southwestern Australia. *J. Climate,* 6, 1356 - 1367.