8-2004

Lower Yilgarn catchment appraisal 2003

D G. Cummins

Recommended Citation

Cummins, D G. (2004), *Lower Yilgarn catchment appraisal 2003*. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 276.

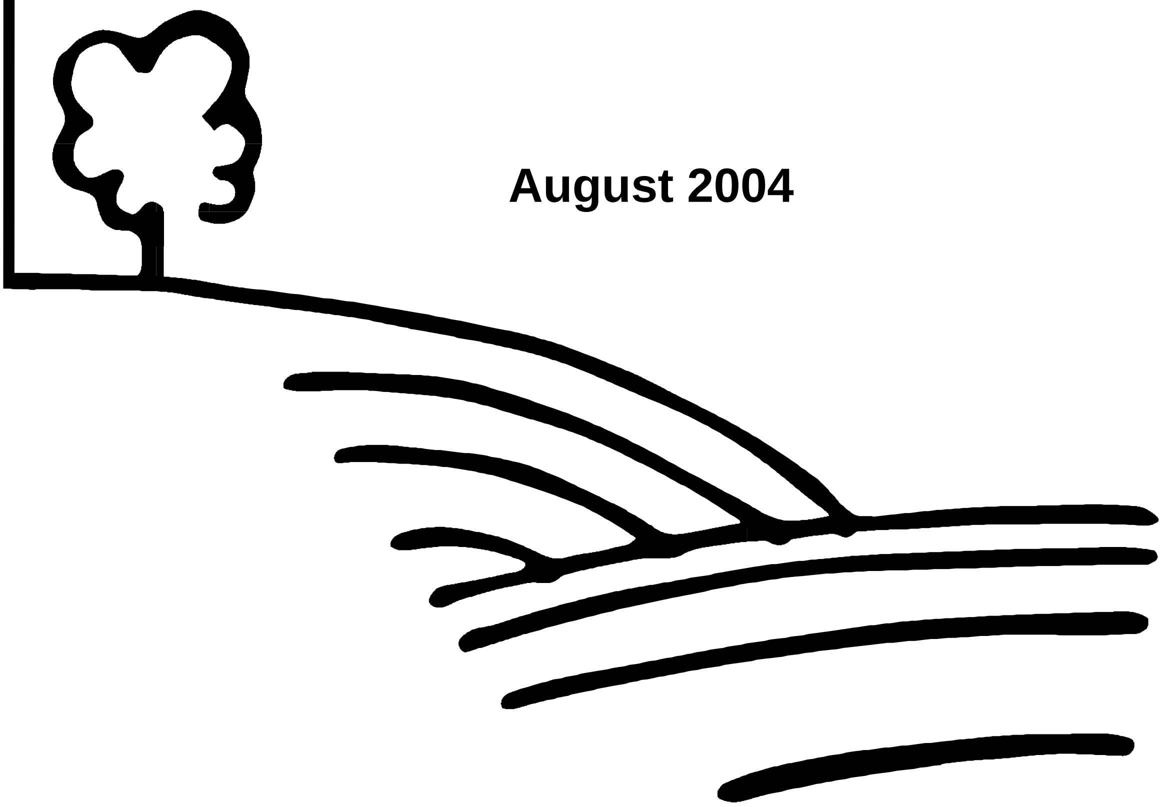
Department of Agriculture
Government of Western Australia

LOWER YILGARN

CATCHMENT APPRAISAL 2003

Compiled by Don Cummins

August 2004



RESOURCE MANAGEMENT TECHNICAL REPORT 276

ISSN 1039-7025

Resource Management Technical Report 276

Lower Yilgarn

Catchment Appraisal 2003

Compiled by Don Cummins
for the Central Agricultural Region
Rapid Catchment Appraisal team

August 2004

Department of Agriculture
Government of Western Australia

CONTENTS

SUMMARY

This report describes the soils, hydrology, natural vegetation and farming systems of the Lower Yilgarn Catchment and provides information on the threats to agriculture, infrastructure and natural resources caused by land degradation.

Lower Yilgarn covers 867,000 hectares in the eastern wheatbelt. The catchment drains into the Yilgarn River, which is a major tributary of the Avon River. The climate is Mediterranean with cool wet winters and hot dry summers and the 10-year average annual rainfall is approximately 330 mm.

The dominant agricultural systems are primarily broadacre with winter cropping and livestock the main industries. Crops grown include wheat, barley, lupins, oats and canola, and the main livestock focus is sheep for wool and meat.

Soils and landscapes are variable, with shallow loamy duplexes, sandy earths and loamy earths comprising 52 per cent of the catchment. Soil degradation issues include (in order of magnitude): subsurface compaction, soil structure decline, water repellence, subsurface acidification, wind erosion, phosphorous export and waterlogging.

Salinity currently affects 3.8 per cent of the catchment (33,000 ha) and 20 per cent (170,000 ha) could be threatened by shallow watertables in the future.

Waterlogging and, in some areas, water erosion are major risks, that can be controlled by constructing well-planned and designed earthworks. Grade banks on sloping land provide an important tool to manage surface water, which should be treated as a resource and used on-farm. Safe disposal of surface water to waterways should be considered a secondary alternative.

The catchment has a very low proportion of remnant vegetation – approximately 158,000 ha (18 per cent), of which shallow watertables affect about 43,370 ha (5 per cent).

1. INTRODUCTION

Rapid Catchment Appraisal (RCA) aims to document salinity risk and management options by addressing all threats to the natural resource base, rather than isolating salinity as a separate issue.

This report summarises current information on risks and impacts to agricultural production and natural resources within the Lower Yilgarn Catchment. It also identifies suitable options to manage such risks. Land managers are urged to use this report as a starting point and to gather further information and support from the sources listed.

The Department of Agriculture team responsible for implementing the RCA process and this report comprised:

- Don Cummins (Team Leader, Northam)
- Shahzad Ghauri (Groundwater Hydrologist, Northam)
- Harry Lauk (Land Conservation Officer, Northam)
- Susie Murphy-White (Development Officer, Farming Systems, Merredin)
- Sally Phelan (Development Officer, Lake Grace)
- Shahram Sharafi (Hydrologist, Merredin)
- Josh Smith (GIS Officer, Northam)
- Henry Smolinski (Soil Research Officer, South Perth)
- Ian Wardell-Johnson (Land Conservation Officer, Narrogin)

The report has been divided into three sections: the natural resource base, catchment risks and management options and impacts. When reading the report it is important to refer between the section chapters in order to gain an understanding of how different risks and management options affect the agricultural resource base.

2. NATURAL RESOURCE BASE

2.1 Study area

Don Cummins

The catchment area is 867,400 hectares and covers parts of the shires of Mt Marshall, Trayning, Kellerberrin, Nungarin, Narembeen and Merredin (Figure 2.1). The lower section incorporates the Wallatin Creek and O'Brien catchments (north of Doodlakine) that make up the regional Catchment Demonstration Initiative project.

The centre point of the study area is located at latitude 117:51:50, longitude 31:11:55.

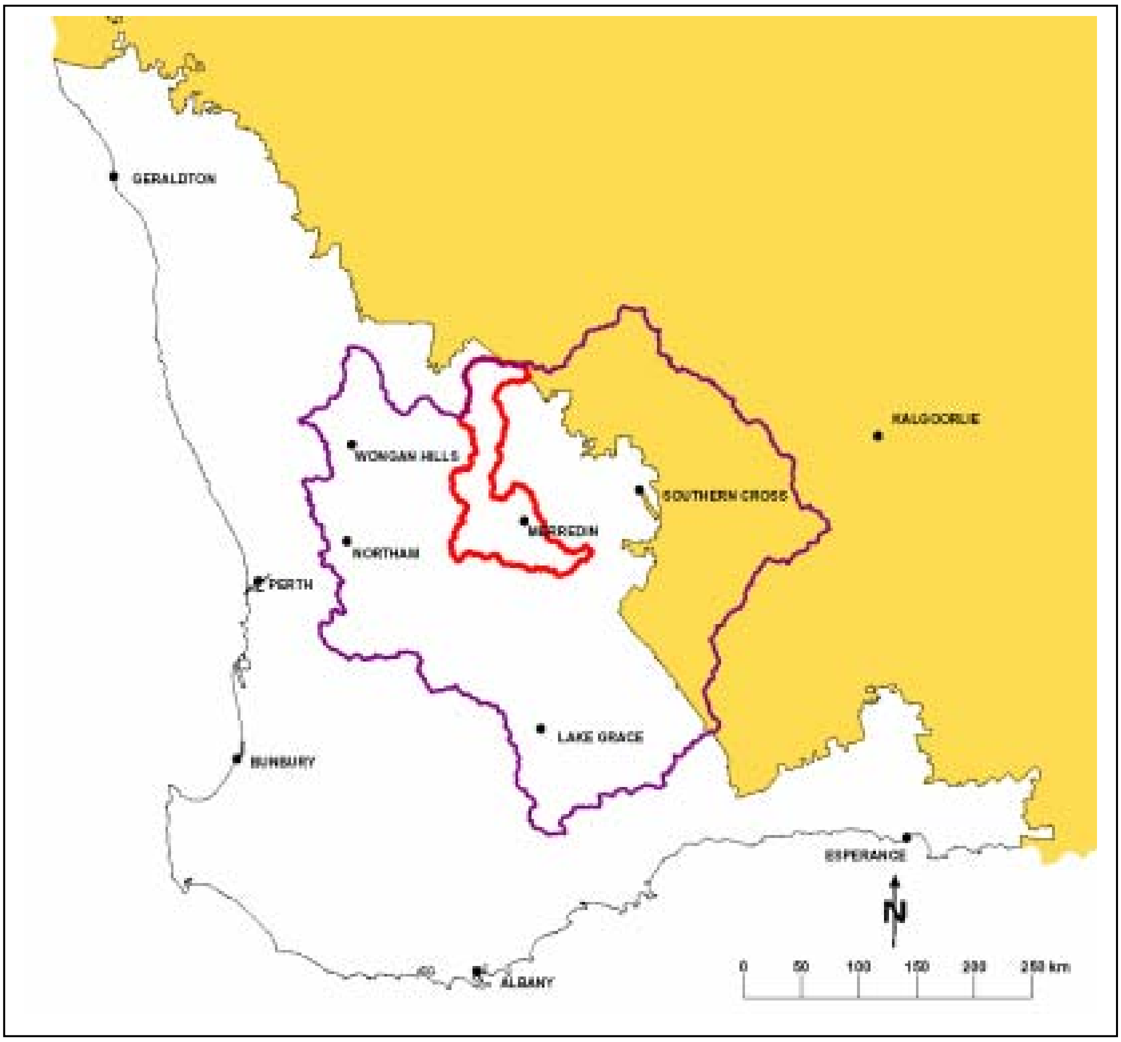


Figure 2.1: Catchment location.

2.1.1 Topography

The landscape is gently undulating with low relief and elevation commonly between 250-400 m. Drainage divides are wide and slopes are long and gentle (2-8 per cent). The main valleys are very wide (2-6 km) with a very low gradient and commonly contain salt lakes in combination with low dune systems.

Surface drainage in northern areas is poorly defined and is often made up of small, unconnected salt lake chains. From Lake McDermott (near Bencubbin) south, drainage becomes better defined. Water from this system feeds into the Bandee Lakes (near Hines Hill) and the Yilgarn River, which runs to the Yenyenning Lakes (outside the catchment boundary) and eventually the Avon River.

2.1.2 Infrastructure

Infrastructure assets are detailed in Table 2.1. Assets of significance include the Goldfields water pipeline, major towns, the east-west rail line and Great Eastern Highway.

Table 2.1. Infrastructure

Infrastructure asset type	Assets
Major towns	Merredin, Kellerberrin, Trayning, Bencubbin and Beacon
Other towns/sidings (incorporating CBH structures)	Yelbeni, Kununoppin, Doodlakine, Hines Hill, Nukarni, Welbungin
Highways/MRWA roads	185 km
Class 1 sealed roads	799 km
Class 2 unsealed roads	2601 km
Railway line	132 km of spur line (some disused), 74 km of east-west railway line
Pipeline	108 km of Water Corporation scheme water pipeline (including 60 km of Goldfield's pipeline)

2.1.3 Climate

Average annual rainfall over the last 10 years for Beacon, Trayning and Kellerberrin is 330 mm and average temperatures are 25°C maximum and 11°C minimum. General climate trends identified during this period include:

- The years 1994, 1997, 1998 and 2002 had below average rainfall for all centres. The most severe dry period was 2002, with an average 40 per cent decrease in annual rainfall across the three sites. The second driest year for all recording locations was 1994 (an average of 33 per cent less rainfall).
- The years 1995 and 1999 were the wettest in the past 10 years, with 1999 recording an average 56 per cent increase in average annual rainfall across all sites, while in 1995 there was a 29 per cent increase.
- Beacon and Kellerberrin have fared the worst in regards to rainfall and both locations have recorded six below average rainfall years since 1994. The worst years being 1994 and 2002, when rainfall was approximately 36 per cent less for both years.
- There have been no significant changes in maximum or minimum temperatures over the past 10 years. Only in a single year (1994) has recorded a 1°C higher maximum temperature across all centres.
- Out of growing season rainfall was significant in 1995 and from 1999 to 2001 (Figure 2.2) corresponding with above average rainfall years for all centres. As such, out of growing season rainfall is generally unreliable, making longer term planning for warm season crop establishment difficult. In many instances such rainfall has fallen in significant events

over relatively short periods of time, e.g. in March 1999 Beacon received over half its average annual rainfall (185 mm) in a period of four days. Such events in summer/early autumn can have impacts on recharge for groundwater tables and can cause severe water erosion problems for paddocks with low levels of ground cover. In contrast, 2003 could probably be considered the best cropping season in the last 10 years, due to the majority of rainfall falling in the growing season (only Trayning received 1.2 per cent below average rainfall).

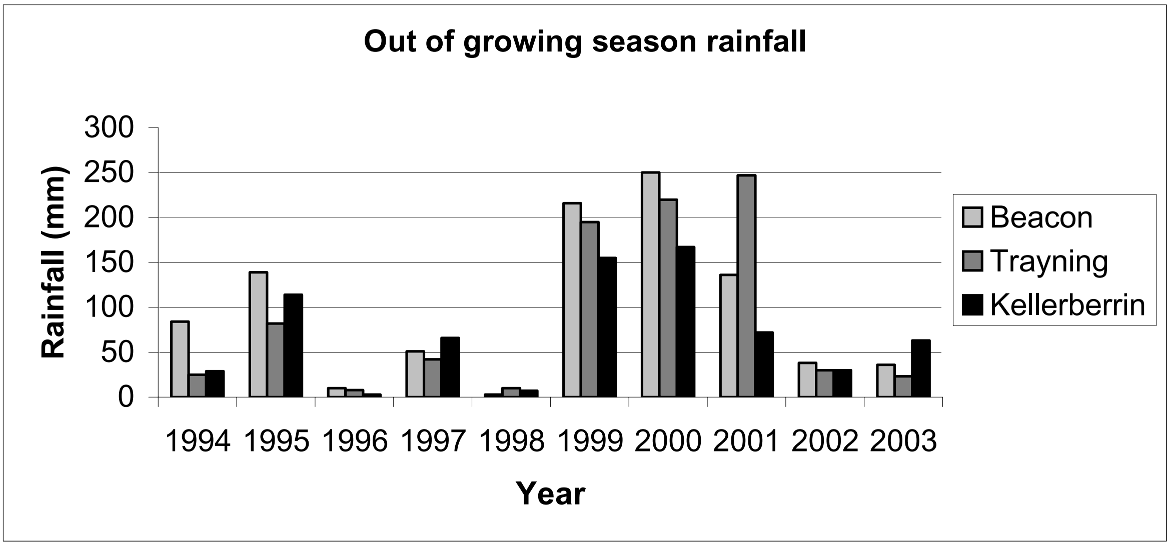


Figure 2.2: Out of growing season rainfall.

2.2 Hydrogeology

Shahzad Ghauri

2.2.1 Geology and geomorphology

The catchment is located on the Yilgarn Craton, which formed over 2500 million years ago. Most rock outcrop in the area is granite and adamellite (Chin 1986). Numerous dolerite dykes have intruded the bedrock and often delineate fractures and possible faults. These dykes are dark-coloured, mostly medium-grained rocks and they often cross the catchment's main flow direction, sometimes forming barriers to groundwater movement.

Soft, weathered rock and transported materials are known as 'regolith'. Regolith profile thickness is generally restricted to about 30 m depth, however some bores have been drilled to around 60 m (e.g. Merredin).

2.2.2 Aquifers

Unconfined (perched) aquifers are formed in the more porous, sandy soils, causing some waterlogging and seeps on middle to lower slopes. This is particularly the case for the northern and south-eastern areas, in the Bonnie Rock (258Br), Kwolyin (258Ky), and Tandegin (258Ta) soil landscape systems (see Appendix A1).

A deeper continuous saprock aquifer extends over most of the catchment and subcatchment to catchment scale intervention would be required to have any major impacts on this system (see Flowtube scenarios Figure 4.1). This aquifer occurs at the border between weathered and fresh basement rock.

Large palaeochannel aquifers are present beneath the salt lake chain that runs in a north south direction. Exploratory drilling indicates that palaeochannel depth can be up to 110 m in depth in places. These systems contain massive quantities of acidic, highly saline groundwater.

2.2.3 Groundwater depth

Two-thirds of bores are located within valleys and have saline watertables within a few metres of the surface. From this, it can be inferred that local groundwater equilibrium has probably been reached and as such groundwater will continue to rise and fall with each season. In upper slope areas, groundwater is generally greater than 8 m in depth and continues to rise. This is likely to result in salinity occurring at change of slope locations, adjacent to currently saline areas.

Figure 2.3 shows how groundwater levels may rise into the future at various locations. The main observation is that bores with deeper watertables take longer to rise to the surface, with major salinity development expected after 2030. George and Kingwell (2003) used pre-clearing watertable depth across the Central Agricultural Region to determine an approximate 'time to salinisation' for different regions. In their report, eastern zones were found to have a longer period until groundwater equilibrium (majority of salinisation expected after 2030 and before 2075). The basic groundwater projection below confirms this prediction.

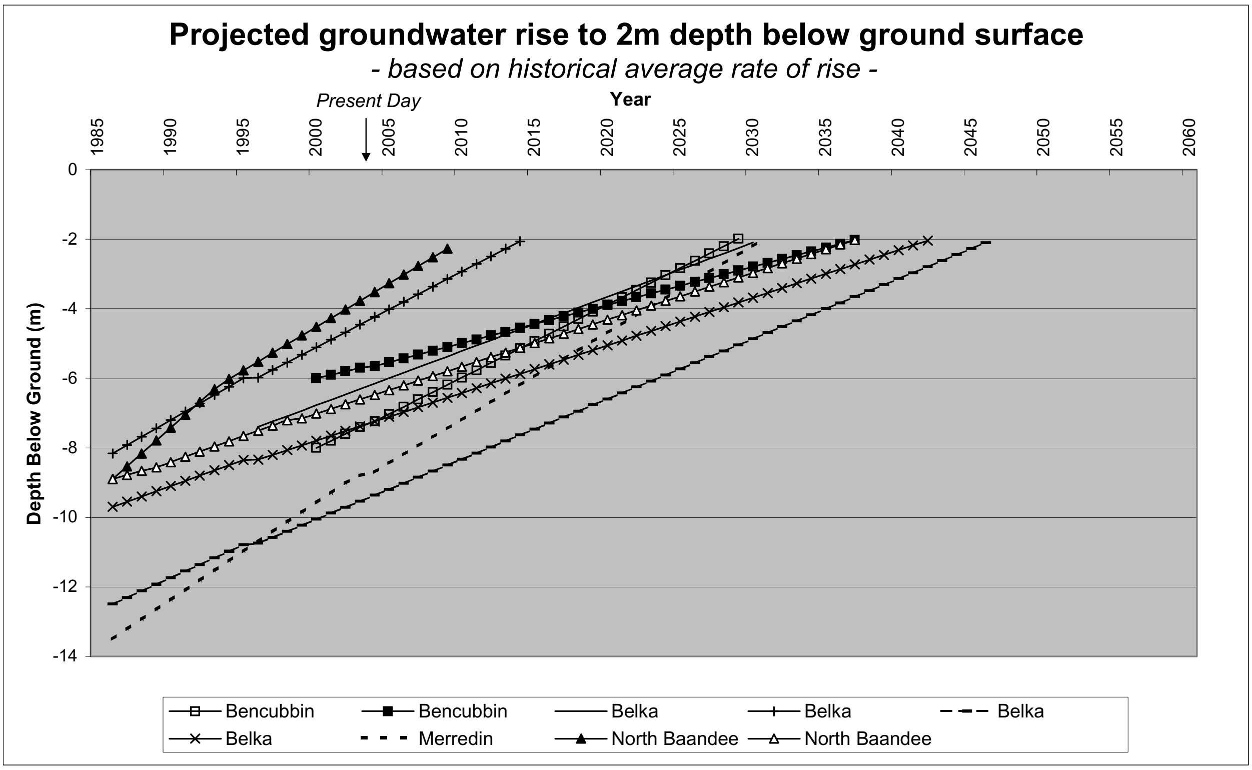


Figure 2.3: Projected groundwater level changes in some Lower Yilgarn bores.

Historical average rates of rise were used to project watertable depth, however it is often the case that rates of rise will decay or lessen as they near the surface. The implication of this is that the time required to reach 2 m depth below the ground surface may be slightly longer than that illustrated in Figure 2.3.

Bencubbin bores in Figure 2.3 have groundwater at 6–8 m below the ground surface and these are projected to reach < 2 m from the surface within 25 to 30 years. Two North Baandee bores are expected to have groundwater close to the surface by 2020 and 2040 respectively and this is supported by Flowtube predictions (Figure 4.1). Bores found in the Belka area display greater depth to groundwater and are not expected to near the surface until 2035–2055.

2.2.4 Groundwater quality

Perched (sandplain) aquifers often have fresh to brackish groundwater (< 900 mS/m) and are more common in the north and south-east because of the dominance of coarser textured soils. Deeper saprock aquifer groundwater, from subcatchments, are saline and often range between 3000 mS/m to 5000 mS/m. George and Frantom (1987) studied the Beacon and Welbungin catchments and found groundwaters were extremely saline at around < 8000 mS/m.

Catchment morphology accounts for the lack of spatial variation in groundwater salinity. Many short subcatchments converge into the narrow north-south trending Lower Yilgarn valley, which has very high groundwater salinity. Salt loads from these subcatchments increase rapidly as groundwater merges into the highly saline groundwater of the main valley.

Groundwater pH varies from highly acidic (pH < 4) to slightly alkaline (pH ~ 7.5). Recent data reveals that highly acid groundwater is widespread. Acid groundwater has the potential to affect agricultural production and there are environmental concerns regarding its disposal from deep drains and pumping systems.

2.2.5 Water resources

Data from the Water and Rivers Commission shows that several hundred bores have been drilled over time into sandplain aquifers, saprock, or fractured rock aquifers. Of these bores, a few hundred records show either groundwater yield estimates or salinity measurements. Twenty-one bores within Lower Yilgarn had both yield and salinity quantified. As can be seen in Figure 2.4, high yielding bores with stock quality water or better are not present in great number. These bore sites are also marked on Figure 2.5.

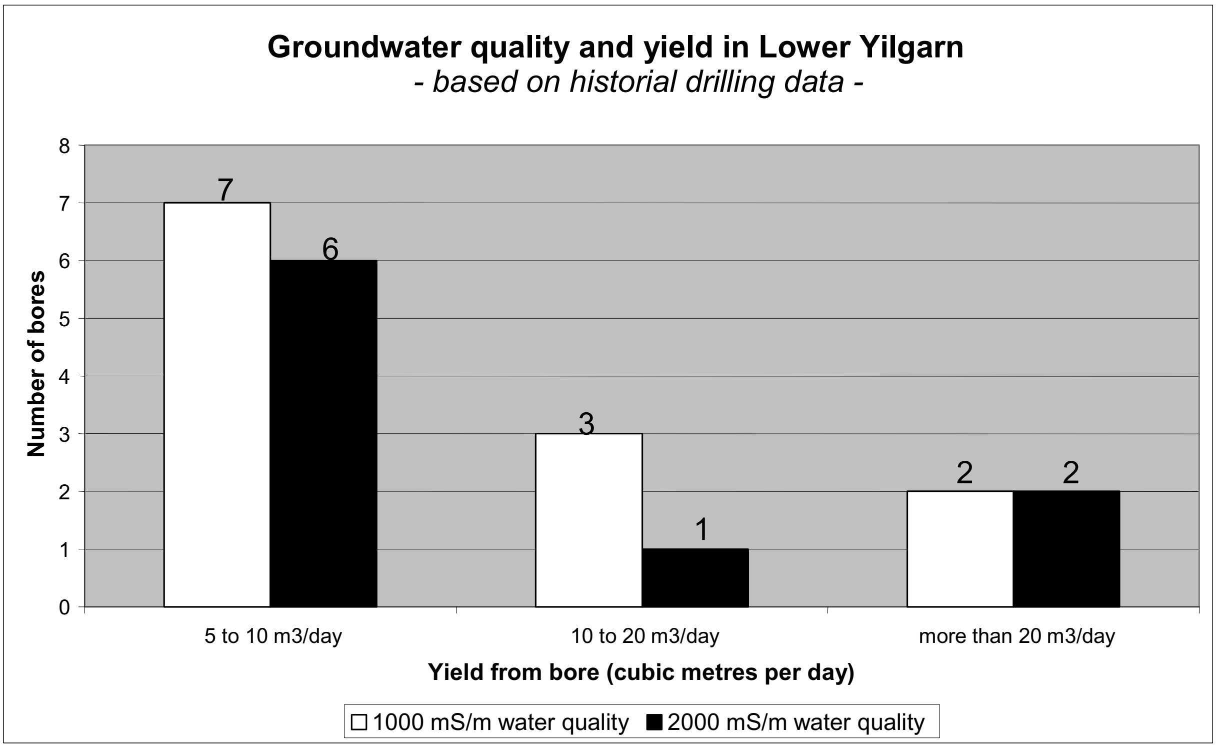


Figure 2.4: Groundwater quality/yield comparison of exploratory bores.

Drilling log information indicates that between 2 m to 6 m of sands/gravels were found at the selected drill sites. This means that landscape considerations were made when locating the bores, in order to reduce the likelihood of highly saline water being encountered. Landholders can follow this example when looking for fresh water. Potential drill sites should have at least 2–6 m depth of sand/gravel present at the surface, should not be located near major drainage lines or lie in upland areas where ground/surface water meet. The catchment soil-landscape systems best suited to groundwater resource drilling include the Bonnie Rock System (258Br), Kwolyin System (258Ky), and Tandegin System (258Ta) (see Appendix A1).

Water and Rivers Commission (WRC) data from 127 bores, including bores on upper slopes of catchments adjacent to the study area, shows that drilling in suitable soil-landscape systems enhances the likelihood of success (Figure 2.6). At the time of drilling and without considering yields, 40 per cent of bores encountered were likely to have good stock quality groundwater (< 1000 mS/m) and another 35 per cent of bores had stock quality groundwater (1000 mS/m to 2000 mS/m).

It is important to note that many WRC bores were drilled decades ago and it is thought that any formerly fresh-brackish resources may have been contaminated by rising saline groundwater bodies and/or additional leaching of salts from the regolith profile since. For this reason, it is advised that time and money may be better spent on managing and harvesting surface water resources rather than those located underground.

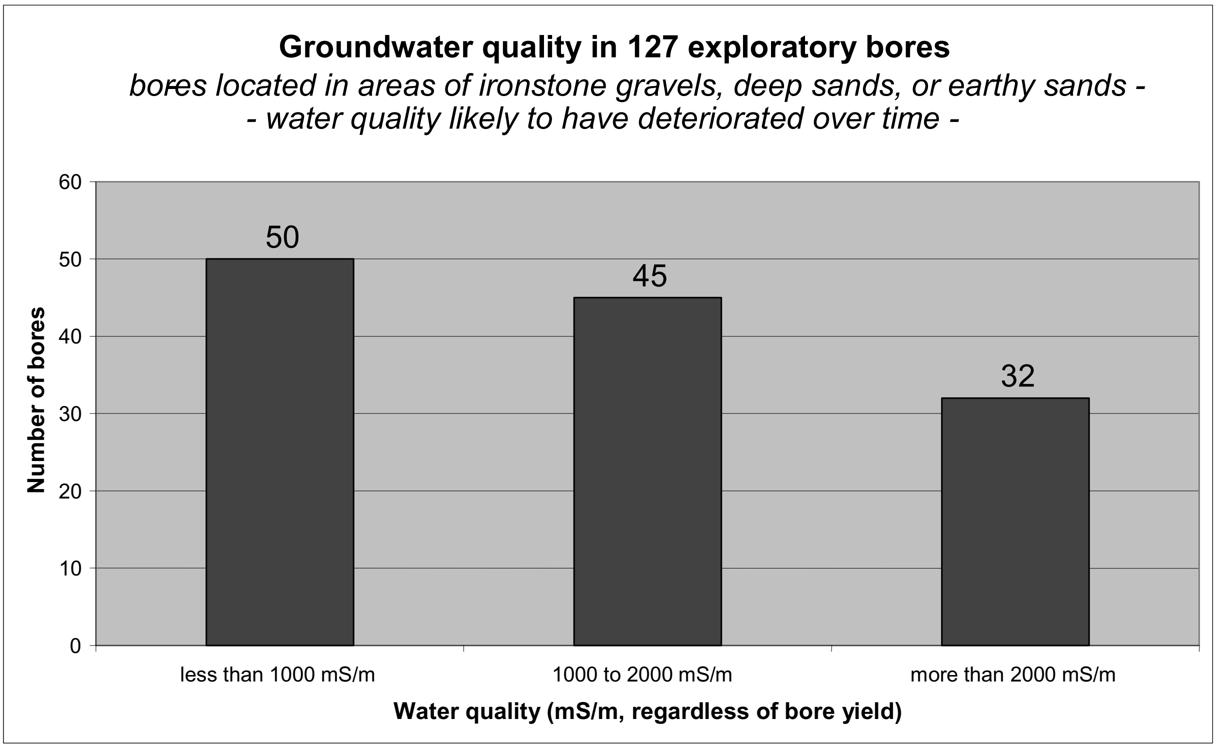


Figure 2.6: Groundwater quality found in exploratory bores in Lower Yilgarn.

There is insufficient WA Department of Agriculture bore information to identify potential groundwater targets. As a general rule, fresh to brackish water is usually found in mid to upper landscape positions, close to sandy soils or rock outcrops. From experience in the area, sumps or depressions in small to moderate sandplain subcatchments (20-100 ha) are also worthy of test drilling.

The Geological Survey of Western Australia published two groundwater reports in the Merredin area (Laws 1981 and 1989), however no groundwater data or publications for the Trayning, Bencubbin and Beacon areas were found. The conclusion reached is that geological conditions are not favourable for large supplies of groundwater, however in coarse textured areas there may be a slight chance of obtaining a supply of 50 m^3 to 100 m^3 per day.

2.3 Soil–landscapes

Henry Smolinski

Soils of the catchment can be grouped into soil groups (Schoknecht 2002) that are managed similarly during broadacre agriculture. These soil groups have been combined into soil supergroups to simplify complex soil-landscape maps. Figure A1.1 provides a description of nine soil-landscapes units at the broad system level.

The catchment area was assessed as part of five soil-landscape surveys carried out by CSIRO Division of Soils and Department of Agriculture.

The mapping projects are listed as follows:

- Kellerberrin Survey (McArthur 1992)
- Merredin Survey (Bettenay and Hingston 1961, 1964)
- Bencubbin (Grealish and Wagnon 1995)
- Corrigin (Verboon and Galloway, in prep.)
- Southern Cross (Frahmand, in prep.)

From this information four common soil supergroups have been identified that account for 62 per cent of the catchment (Table 2.2). These supergroups are:

- shallow loamy duplexes, which occupy 21 per cent, mostly on hill tops, slopes and valley floors;
- sandy earths (typically sandplain soils), which occupy 19 per cent and dominate the northern and central areas;
- loamy earths, at 12 per cent and which are found on lower slopes; and
- deep sandy duplexes at 10 per cent.

Other less prevalent but still significant soil supergroups are ironstone gravelly soils (8 per cent) and deep sands (8 per cent). Soil supergroups provide a basis for any future Land Management Unit mapping. Figure 2.7 illustrates the distribution of all the soil supergroups.

Table 2.2. Soil groups

Soils and abundance	Common soil description and landscape position	Dominant soil components (percentage of catchment)
Shallow loamy duplex 184,824 ha 21.3%	Soils with a loamy topsoil and a texture contrast within 30 cm Crest, sideslopes and valley floors	Alkaline grey shallow loamy duplex (8.7%) Alkaline red shallow loamy duplex (6.8%) Yellow/brown shallow loamy duplex (4.5%)
Sandy earths 163,862 ha 18.9%	Soils with sandy surface and grading to loam by 80 cm Sandplains, colluvial and alluvial sediments	Yellow sandy earth (8.3%) Red sandy earthy (6.3%) Acid yellow sandy earth (2.6%) Pale sandy earth (1.5%)
Loamy earths 105,256 ha 12.1%	Soils with a loamy profile or may grade to clay by 80 cm Wind-blown lake sediments and colluvium on lower slopes	Calcareous loamy earth (8.9%) Red loamy earth (1.7%) Brown loamy earth (0.8%)
Deep sandy duplex 86,439 ha 10%	Soils with a sandy surface and a texture contrast at 30–80 cm Colluvial slopes and valley floors	Grey deep sandy duplex (6.4%) Alkaline grey deep sandy duplex (1.3%) Red deep sandy duplex (1%) Yellow/brown deep sandy duplex (0.8%)
Ironstone gravelly soils 74,042 ha 8.5%	Soils containing common to abundant ironstone gravel usually associated with crest and rises	Deep sandy gravel (1%) Duplex sandy gravel (1.2%) Loamy gravel (5.6%) Shallow gravel (1%)
Deep sands 68,891 ha 7.9%	Sands > 80 cm deep with a sand to clayey sand texture Sandplains, spillway sands and depressions in lateritic terrain	Yellow deep sand (5.2%) Gravelly pale deep sand (1.5%) Pale deep sand (1.1%)
Shallow sandy duplex 58,631 ha 6.8%	Soils with a sandy surface and a texture contrast within 30 cm Colluvial slopes and valley floors	Alkaline grey shallow sandy duplex (3%) Grey shallow sandy duplex (2.5%) Yellow/brown shallow sandy duplex (1%)
Wet or waterlogged soils 33,358 ha 3.9%	Soils seasonally wet within 80 cm of the surface for major part of the year Drainage systems and salt lakes	Salt lake soils (1.2%) Saline wet soil (2.5%)
Rocky or stony soils 23,208 ha 2.7%	Commonly bare rock and shallow sandy to loamy soils containing abundant rock fragments and stone Crest and hillslopes	Bare rock (2.4%) Stony soils (0.2%)
Cracking clays 16,590 ha 1.9%	Hard or self-mulching cracking clay that strongly cracks when dry Valley floors	Hard cracking clay (1.7%)

Soils and abundance	Common soil description and landscape position	Dominant soil components (percentage of catchment)
Shallow sands 14,611 ha 1.7%	Sandy soils with a depth < 80 cm overlying rock or hardpan layer Rocky areas and associated with red-brown hardpan	Yellow/brown shallow sand (0.8%) Pale shallow sand (0.5%) Red shallow sand (0.4%)
Non-cracking clay 12,461 ha 1.4%	Red/brown or grey non-cracking clay Valley floors	Red/brown non-cracking clay (0.9%) Grey non-cracking clay (0.5%)
Deep loamy duplex 7939 ha 0.9%	Soils with loamy topsoil and a texture contrast at 30-80cm. Lower slopes and valley floors commonly on drainage channels	Red deep loamy duplex (0.9%)
Other minor soils 17,289 ha 2.0%	Areas of permanent or near permanent water Soils that could not be described within the main Soil Groups	Red deep loamy duplex (2.0%)

2.4 Agricultural production

Susie Murphy-White

The agricultural production data (ABS 1999) relates to information compiled on a shire by shire basis and has not been adjusted to the Lower Yilgarn Catchment boundary area.

Farming systems are dominated by annual crop and pasture rotations, with a focus on improved pastures in recent years. Crops grown include wheat, barley, oats, lupins, field peas, chickpeas, faba beans and canola.

The total farmed area of the Lower Yilgarn Catchment is 847,000 ha. The largest average farm size is found in the Mt Marshall Shire at 4092 ha and the smallest average farm size 2140 ha in the Kellerberrin Shire. The number of farms has slightly decreased with the size of the average farm increasing over the last two decades.

The area of farmland comprises 50 per cent of cropping, while improved pastures (subterranean clover, medics, bisserulla and serradella) and unimproved pastures cover about 18 per cent. In 1983 the cropping area (cereals and lupins) covered about 41 per cent of the farmed area, with pastures occupying 33 per cent. This shows the change in farming systems from an almost equal mix of livestock and cropping to more cropping and less livestock over the last 20 years. Fluctuations in commodity prices, especially for sheep and wool may account for this change.

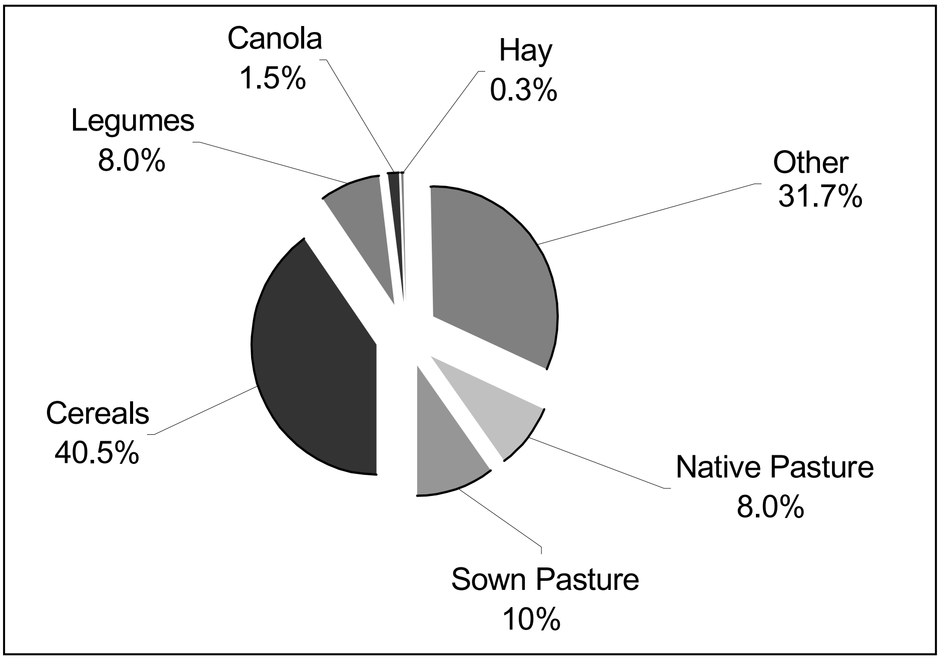


Figure 2.8: Enterprise distribution as percentage of farmed area across the whole shire. (Source: ABS 1999)

The trends from 1983 to 1999 show the area of native and sown pasture has decreased by almost half and the area planted to cereals has not shown much change. The amount of grain legumes present in the farming system have increased, with the emergence of pulses in the early 1990s, as an alternative to a lupin rotation. No canola was grown in 1983 and the amount of hay has decreased by half over this time period.

The total agricultural Gross Value of Production (GVP) in the Bruce Rock, Kellerberrin, Merredin, Trayning and Mt Marshall shires in 1999 was $200 million (ABS 1999). Of this production, crops contributed 78 per cent while animal products (wool and meat) contributed 15 per cent and livestock (sheep, cattle and pigs) 7 per cent. The highest GVP from crops is in the Mt Marshall and Trayning shires (82 per cent and 81 per cent) while Bruce Rock has the highest level of animal products 17 per cent and Merredin has the highest livestock production at 10 per cent. The GVP in 1983 was worth $141 million, 84 per cent contributed to by crop production, 7 per cent from livestock and 9 per cent animal production. A slight increase is observed in the crop and animal production from 1983 to 1999.

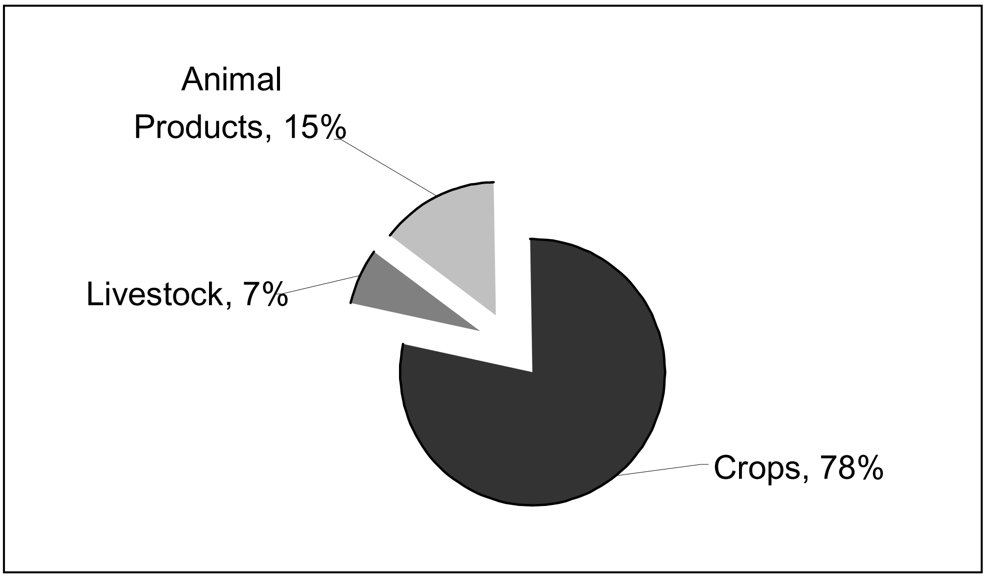


Figure 2.9: Average GVP for major categories of agricultural production in the shires of Bruce Rock, Kellerberrin, Merredin, Mt Marshall and Trayning.
(Source: ABS 1999)

BankWest financial benchmarking (2002) from the Merredin and Nungarin branch areas shows that the majority of farming enterprises are still underperforming in regards to operating profit when compared to the top 25 per cent (Figure 2.10). This is particularly evident in 1997 and 1998 when below average rainfall was received and in 2000, when this area had the majority of its annual rainfall outside the growing season.

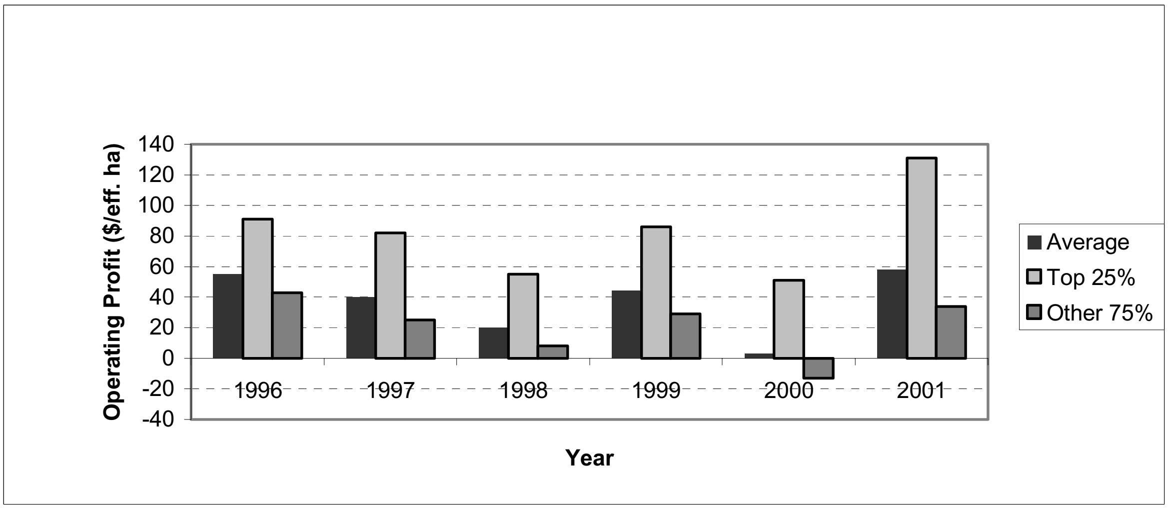


Figure 2.10: Operating profit ($/eff. ha) – north-eastern wheatbelt.
(Source: BankWest Benchmarks)

Average wheat yields have generally increased, with the highest average wheat yield in the Trayning Shire (2.15 t/ha) in 1999/00. Below average rainfall was received in most areas in 2000/01 growing season and wheat yields declined. Dry seasonal conditions were experienced again in 2002/03 reflecting the lowest below average yields of 0.33 t/ha in the Mt Marshall Shire.

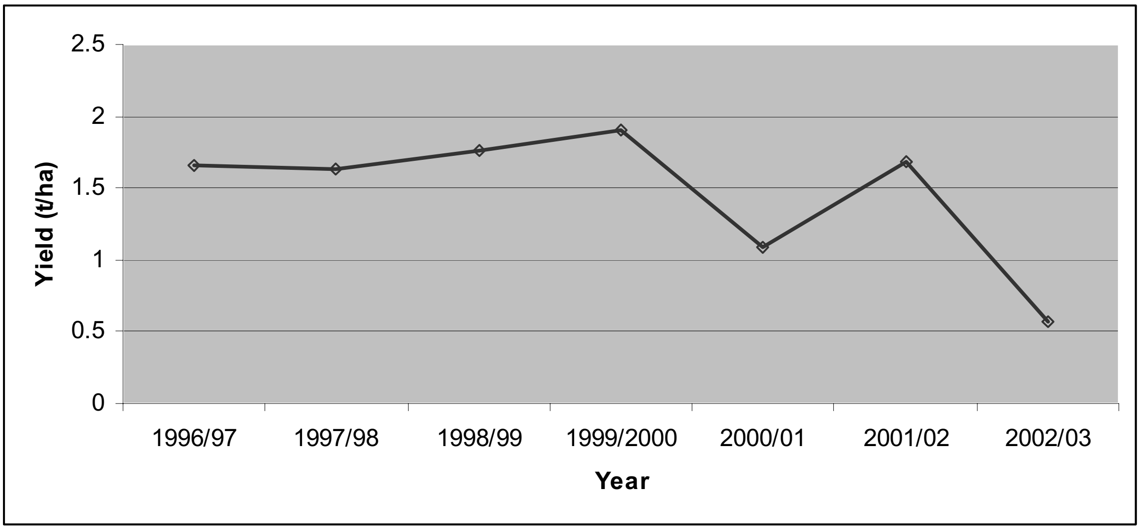


Figure 2.11: Average wheat yields for the Lower Yilgarn Catchment. (Source: CBH estimates)

Since the 1970s land values across the five shires in the Lower Yilgarn Catchment area have gently increased with prices fluctuating as a result of the general economy, seasonal conditions and commodity prices. The highest average price was $600/ha received in 1998 and 1999 in the Kellerberrin Shire.

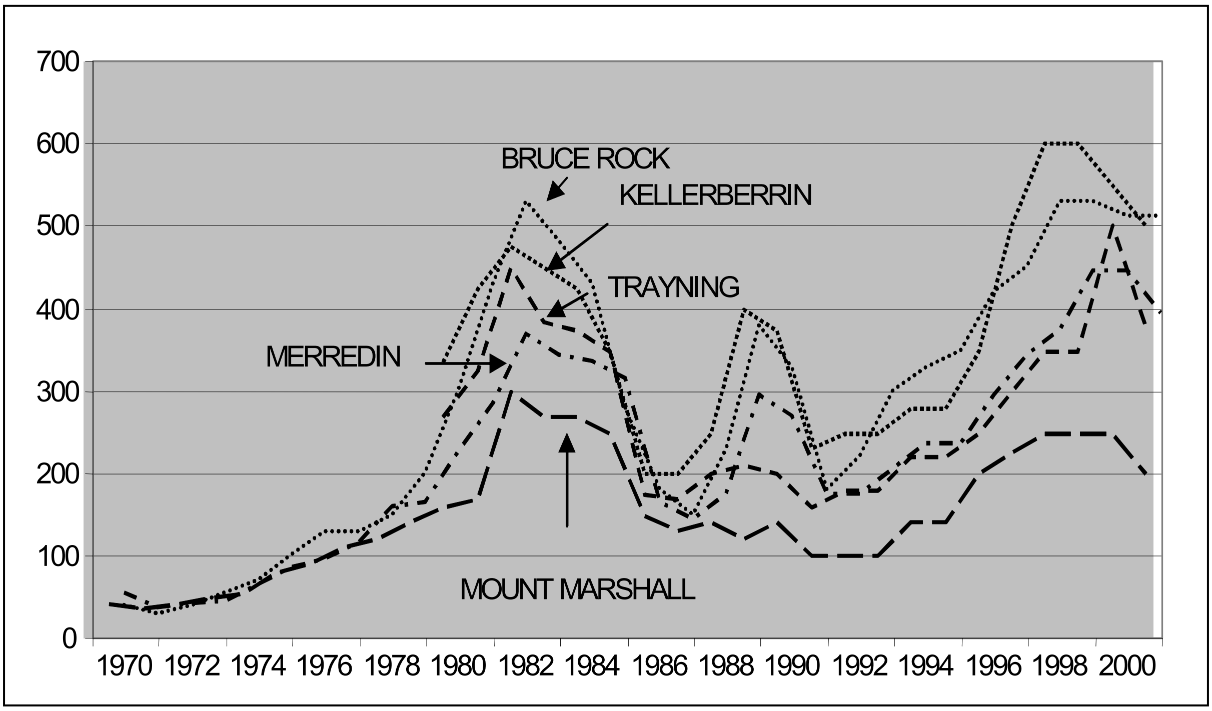


Figure 2.12: Average land values 1970-2001 for the shires in the Lower Yilgarn Catchment. (Source: Valuer General's Office)

2.5 Native vegetation

Sally Phelan

The Lower Yilgarn has approximately 158,000 ha (18 per cent) of remnant vegetation (Figure 2.13). This is above the eastern wheatbelt average of around 10 per cent. The remaining vegetation is dominated by casuarina, acacia and melaleuca shrublands with large areas of York gum, salmon gum, gimlet and morrel woodlands. Table 2.3 shows the dominant vegetation types remaining in the catchment.

Table 2.3. Dominant remaining vegetation associations

Beard's vegetation classification	Area remaining (ha)	Area remaining (% of total vegetation)
Shrublands; thicket, acacia-casuarina alliance	26,966	17
Shrublands; acacia, casuarina and melaleuca thicket	17,155	11
Medium woodland; wandoo, York gum, salmon gum, morrel and gimlet	15,522	10
Shrublands; *Allocasuarina campestris* thicket	14,970	9
Medium woodland; York gum, salmon gum and gimlet	13,047	8
Shrublands; York gum and *Eucalyptus sheathiana* mallee scrub	10,994	7
Medium woodland; York gum, wandoo and salmon gum	10,435	7

Other significant factors include:

- Average remnant size is 12 ha.
- Most remnants are found on sandy or granite hilltops, and saline or low lying areas. There is a low representation of mallee vegetation in the catchment (less than 10 per cent).

3. CATCHMENT RISKS

3.1 Salinity and groundwater

Shahzad Ghauri

3.1.1 Groundwater trends

There are 249 bores in the catchment, of which about 70 have more than 20 monitoring records spanning greater than five years. Two-thirds of the 70 bores display shallow piezometric heads (< 1–2 m) which indicate that some level of soil salinisation at these locations has already occurred or is currently taking place. The Beacon, Bencubbin, Merredin, North Baandee, Welbungin and other Department bores on private property have been relied upon for interpreting groundwater trends in this report.

Groundwater trends in the catchment are variable (Figure 2.5). Sustained deep watertable rise is displayed and where watertables are deep (> 8 m below ground level) rates of rise are likely to continue towards a groundwater equilibrium. Rates of rise beneath hill slopes vary considerably and commonly range between 0.15 and 0.30 m/yr (Ghauri 2004).

3.1.1.1 Rising trends

Middle and upper slope areas show the greatest rates of groundwater rise, with most upper catchment bores displaying rising trends over both the short and long term, in this case from 3 to 18 years. Rates of rise range between 0.1 m and 0.5 m per year, with rising bores more frequently ranging between 0.1 and 0.3 m/yr.

Variations in groundwater salinity do not seem highly correlated with rates of rise, meaning that both groundwater rise is occurring by both local recharge processes and regional groundwater rise.

3.1.1.2 Falling trends

All falling trends appear associated with declining rainfall and most of these bores are located in lower landscape or valley positions (e.g. Beacon, Bencubbin, Merredin) and/or proximal to discharge areas. Reduced in situ rainfall recharge and run-off contributions from slopes may explain this phenomena.

3.1.1.3 Static bores

Many bores show both rising and falling trends of less than 0.1 m/yr over various monitoring periods. The bulk of these bores are located in lower slope or valley/discharge areas. The changes may be related to reductions in rainfall/run-off in recent years and/or discharge through capillary action. Groundwater in these areas has reached local equilibrium, watertables are shallow (< 1–2 m below ground), and display only seasonal responses to rainfall.

3.1.2 Current extent of salinity

The catchment has 33,000 hectares of saline land (3.8 per cent), based on Land Monitor data (Figure 3.1). Land Monitor mapping of salinity does show some areas that are inaccurately mapped as saline (e.g. soil erosion areas) or non-saline (mildly saline barely grass flats), however, these represent only a small proportion of the entire area of the catchment. The Kellerberrin System (258Kb) contains most of the saline land.

Salinity is most common in valley floors but in a recent survey farmers rated salinity occurring at the change of slope as the biggest problem. These areas are where management options should be focussed. Salinity is likely to expand in low-lying areas adjacent to existing salinity, however this expansion is highly dependent on elevation, slope and soil type.

The Bonnie Rock System (258Br), which forms the majority of the upper catchment area, has little or no Land Monitor mapped salinity. The area is made up of gently undulating sandplain, associated slopes and minor rock outcrop. However, water level data indicates that the Beacon area has shallow saline watertables and George and Frantom (1987) confirmed that soils in the area are affected by salinity.

3.1.3 Potential salinity risk

Land height information from Land Monitor indicates that approximately 282,000 hectares (32 per cent) is located in low-lying hazard areas, close to surface water flow paths (Figure 3.2). This estimate is regarded as suitable for first pass regional modelling, however additional refinement of the land height information with local knowledge gives a figure closer to 170,000 hectares (20 per cent, Sharafi 2004, unpublished). Some of these areas could become waterlogged and/or saline if watertables rise sufficiently. Sandy areas and those in proximity to large discharge areas are unlikely to be as severely affected.

A large proportion of primary and secondary salinity has already developed in the main valley of the catchment, evident from the current salinity maps and land height hazard information. Non-saline paddocks in the main valley that border saline land are susceptible to rapid salt accumulation following flood events such as was experienced in 2000.

The majority of additional salinisation is expected to occur in the tributary valleys that lie perpendicular and meet in the Lower Yilgarn valley. These flat areas will be more prone to lateral expansion of salinity because of the inability of their surface and groundwater systems to deal with rainfall recharge. Reducing surface water inundation of these tributary valleys using earthworks will be required to reduce the area affected by salinity.

Almost 40 per cent (300 km) of sealed (Class 1) roads and over 30 per cent (800 km) of unsealed roads are within low-lying areas. The annual cost of repairs and maintenance due to salinity is assessed to be almost $20,000 per kilometre for highways and main roads and around $6600 per kilometre for local and unclassified roads (Kingwell 2003).

Details about Land Monitor can be found by visiting www.landmonitor.wa.gov.au. Accuracy statements of the data sets can be found in CSIRO Mathematical and Information Services (CMIS) Report No. 01/111.

3.2 Soil and land degradation

Henry Smolinski

Employing best management practice is the most important factor to help avoid soil degradation problems, however, many soils have some inherent characteristics that predispose them to certain land management hazards. For example the two most extensive limiting characteristics found in the Lower Yilgarn are subsurface compaction and soil structure decline and these problems may be linked not only to management but soil sodicity, which is inherent.

There are five other significant land management hazards and the most widespread are water repellence and subsurface acidity. Subsurface acidity risk covers about 47 per cent of the catchment. This proportion is of concern because of recent increases in the area of land being cropped. This risk value is probably underestimated.

The land management hazards described following (Table 3.1) are based on the attribution of soil-landscape mapping conducted by the Department of Agriculture. Land qualities are attributed to soil and map units to assist in identifying management, conservation and degradation issues. The results of this analysis concur with discussions held with farmers in the Lower Yilgarn, who considered soil compaction, structure decline and acidity as their most significant land degradation issues.

Table 3.1. Land management hazards

Threat	Area at risk % (and area)	Soil supergroup
Subsurface compaction	91% (789,000 ha)	Deep sand and sandy earths. Coarse-textured sandier soils with less than 5% clay content are most at risk.
Soil structure decline	62% (537,000 ha)	Shallow loamy duplex soils, loamy earths and non-cracking clays.
Water repellence	50% (433,000 ha)	Deep sands, sandy earths and gravelly soils.
Subsurface acidity	47% (407,000 ha)	Deep sands, sandy earths and ironstone gravelly soils. Lighter-textured sands and loams with low organic matter levels are most susceptible.
Wind erosion	47% (407,000 ha)	All soils but especially deep sands and sandy earths. Loamy earths, particularly the calcareous loamy earths are wind-blown sediments which are highly prone to wind erosion when cultivated too dry.
Phosphorous export	35% (303,000 ha)	Wet and waterlogged soils, sandy and loamy duplex soils situated on valley floors, flow lines and areas susceptible to flooding.
Waterlogging	33% (286,000 ha)	Wet and waterlogged soils, sandy and loamy duplex soils.

3.3 Agricultural production

Susie Murphy-White

3.3.1 Biophysical risks

Biophysical risks such as subsurface acidity, salinity, waterlogging, soil structure decline, compaction and water repellence will require a high level of investment, of both time and money, to prevent further degradation. Those issues difficult to reverse will result in changes to farming systems to accommodate the altered landscapes. The treatment of biophysical risks is outlined in Table 4.1.

As an example the risk to agricultural production if salinity spreads, from the current extent of 3.8 per cent (33,200 ha) to the possible extent of 20 per cent, may be a loss of around $18 million worth of production. The area at greatest risk is valley floors and adjacent slopes. This part of the landscape may see changes in enterprise distribution to include more salt bush, salt tolerant perennial pastures and shrubs. Over time the changes in enterprise distribution may include an increase in the proportions of livestock on farm and a decrease of cropping area.

There would also be an estimated loss of $94 million if subsoil acidity was left untreated. It is expected that 47 per cent of the catchment area is at moderate to high risk of subsurface soil acidification. Approximately 796,000 tonnes of lime will be needed to be used by 2020 (one lime application at 1 tonne per hectare every 7–10 years) to reduce the risk to a decline in agricultural production and GVP.

3.3.2 Capacity to invest

The cost of investing in an activity such as natural resource management is often seen as more costly and risky than investing in land. It should also be considered that the capacity for farmers to invest in conservation works is generally driven by high income producing years that provide cash surpluses and improved equity. Figure 3.3 shows that there have been generally no surplus funds on a year in, year out basis between 1998 and 2002.

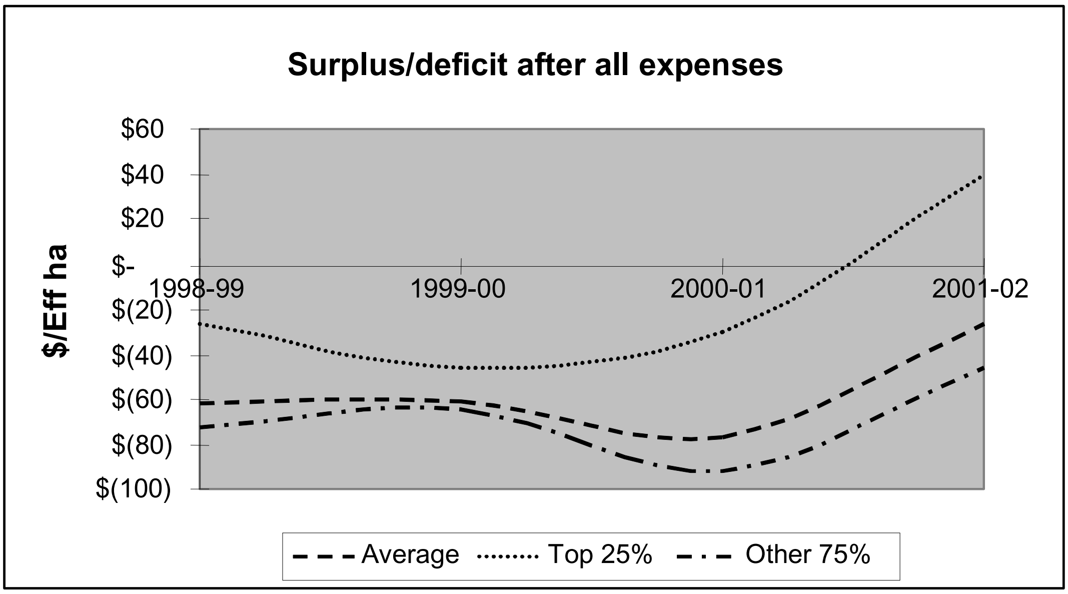


Figure 3.3: Surplus and deficit after all expenses.
(Source: BankWest benchmarks)

Within the eastern wheatbelt since 1998-99 the potential to invest in conservation works has been limited. The top 25 per cent of farmers invest up to $1/ha in the eastern wheatbelt.

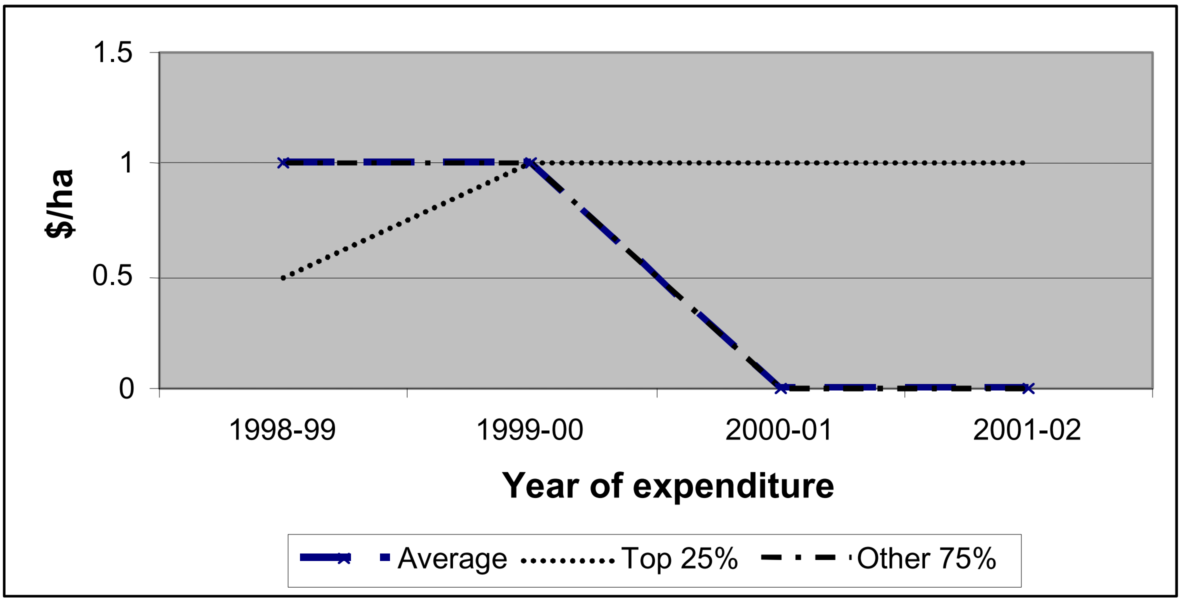


Figure 3.4: Money invested in conservation works.
(Source: BankWest benchmarks)

3.4 Surface water

Harry Lauk and Ian Wardell-Johnson

The surface water risks in the catchment can be summarised as follows:

- Fifty-one per cent of the catchment has slopes of less than 1 per cent but only 7 per cent of soils are wet and waterlogged or valley clay types. This indicates that there are large, broad, flat valley systems with clay soils with low grades usually confined to a narrow band in the valley floor. The potential risks from rising watertables are high, with associated problems being salinity, waterlogging and surface flooding in above average wet years.
- Forty-one per cent of the catchment has slopes between 1 per cent and 3 per cent with 78 per cent of the soils being sandy, sandy loam or loamy type duplex soils. This would indicate that in average to below average rainfall years surface water issues would not be a problem. In such years, poor stock/farm water supplies would be a major issue in the catchment. In above average rainfall years erosion and waterlogging would be expected on sandy/loamy duplex soils.
- In the north of the catchment, surface water management systems to control waterlogging, flooding and in situ drainage should be a priority.
- Targeting the major duplex soils in the catchment for subsurface water/moisture control by engineering or plant based solutions could be considered a lower priority.
- In the Mt Marshall and Trayning shires surface water control on the upper slopes and crests where there is higher run-off is regarded as a priority to help minimise lower slope waterlogging and erosion. This approach would be applicable on similar landscapes in other shires within the catchment.

3.5 Illegal drainage

Harry Lauk and Ian Wardell-Johnson

Many landholders are considering utilising deep drainage to manage groundwater and salinity and there are a number of examples of unnotified drainage found in the area. There are a number of risks and issues associated with illegal drainage:

- Downstream infrastructure, such as roads and culverts, is often at risk. Culverts commonly erode away or silt up.
- Downstream agricultural productivity and natural resources can be threatened.
- Deep drains in the lowest part of the landscape are very vulnerable to high rainfall events. They can also have a very high maintenance cost.
- Best management practice states that deep drains should be installed in small catchments up to 2500 hectares, where the services of a civil engineer are not required.
- Uncoordinated planning can create difficulties when designing and constructing other earthworks up slope.
- Social issues and ill feeling can occur when downstream neighbours are not notified or given the opportunity to comment on drainage plans.
- Legal problems can occur, e.g. under common law. Structures, such as deep drains, should not interfere with, divert or diminish the natural flow characteristics of any flow path. Another issue is that, if a property is sold with illegal drainage in place, the new landholder may fill in the existing drains and the upstream neighbour may be liable to any damage that occurs from his drains. In regards to safe working conditions WorkSafe Western Australia have a code of practice for all types of excavations. This code relates to instances where a person is required to work in an excavation or other opening that is at least 1.5 metres deep.
- The Commissioner of Soil and Land Conservation does not get a chance to assess for on and off-site degradation if drainage isn't notified. It is important to note that for the majority of proposal notifications no objections are lodged. An objection also does not always equal refusal but rather is an opportunity for the applicants and the Commissioner's representative to work together to improve the design to help minimise degradation.

3.6 Native vegetation

Sally Phelan

3.6.1 Remnants at risk from salinity

Currently around 5 per cent (43,000 ha) of existing remnant vegetation is salt affected or waterlogged. This figure includes naturally saline environments such as salt lakes and samphire vegetation and large areas of salmon gum, morrel, blackbutt and gimlet woodlands. Such low lying woodland vegetation is at the greatest risk of secondary salinity from rising watertables.

3.6.2 Fragmentation and biodiversity risks

The fragmentation of native vegetation has major impacts on biodiversity and ecosystem function in the landscape. Isolation of habitats and insufficient habitat size will impact differently on different species, depending on their size and ability to move between remnants (Parsons 2003). In the Lower Yilgarn Catchment, there are over 12,500 remnants. Of these, the average remnant size is 12 ha, with over 84 per cent being less than 10 ha in size. This fragmentation of remnants and lack of connectivity between remnants may limit the ability of flora and fauna to sustain viable populations.

In addition to salinity and fragmentation, biodiversity is at risk due to the following factors:

- livestock grazing the understorey in unfenced remnants;
- increased fire frequency or altered fire regimes;
- nutrient export from agricultural land;
- biosecurity issues such as weed and disease invasion; and
- chemical and fertiliser drift.

4. MANAGEMENT OPTIONS AND IMPACTS

4.1 Groundwater management

Shahzad Ghauri

4.1.1 Managing recharge

Flowtube modelling of the North Baandee subcatchment suggests that widespread plant based recharge reduction may impact future groundwater trends. The time frames calculated by Flowtube also correspond with simple groundwater projections from Figure 2.3.

The results show that under current land management and an estimated 20 mm annual rate of groundwater recharge, lower slope areas close to the main valley will be affected by shallow watertables (< 1 m) within 30 years. This amounts to a considerable proportion of the valley becoming unproductive or suited only to saltland pastures. Flowtube results do not directly correspond to the area of catchment that will be at risk of shallow watertables, as this is highly dependent on catchment morphology and regolith properties. Many sandy surfaced soils and side slopes of the catchment will not be adversely affected.

A base case and two recharge reduction scenarios are presented and these represent differing levels of intervention by all landholders within the entire catchment. The scenarios are as follows:

1. Do nothing – recharge continues at 20 mm/yr (100 per cent of recharge) and current farming systems do not change.
2. Moderate intervention – 25 per cent recharge reduction through minimising annual pasture area, using perennials and other revegetation whilst still cropping similar areas of land each year.
3. High intervention – 50 per cent recharge reduction through widespread adoption of perennial pastures and other recharge reduction measures such as alley farming, tagasaste and oil mallees.

Results show that middle and lower slopes are at risk of salinisation within 30 years and that the onset of salinity in middle slope areas can be delayed by 30 years or more, depending on the level of intervention. Lower slope and valley areas must not be seen to be completely unproductive, as many areas within salinised paddocks will remain highly productive for salt tolerant pastures. Reducing areas of annual pasture in favour of perennial pasture systems and development of saltland pastures will be amongst the most important methods of farm income preservation over the next few decades.

NOTE: Flowtube modelling cited in this report assumes a constant annual rate of recharge. It does not take into account episodic recharge. Episodic recharge forms a major if not dominant mechanism for groundwater rise in the WA wheatbelt. It occurs during high rainfall/flood events and often results in watertables rising and not lowering to their previous, deeper levels. Another major assumption is that all strategies implemented take effect immediately with full potential, e.g. that lucerne planted is evapotranspiring water at its full potential from the moment it is included in the program. All of the above mentioned limitations contribute to a delay in rate of watertable rise, therefore years reported are only indicative guides.

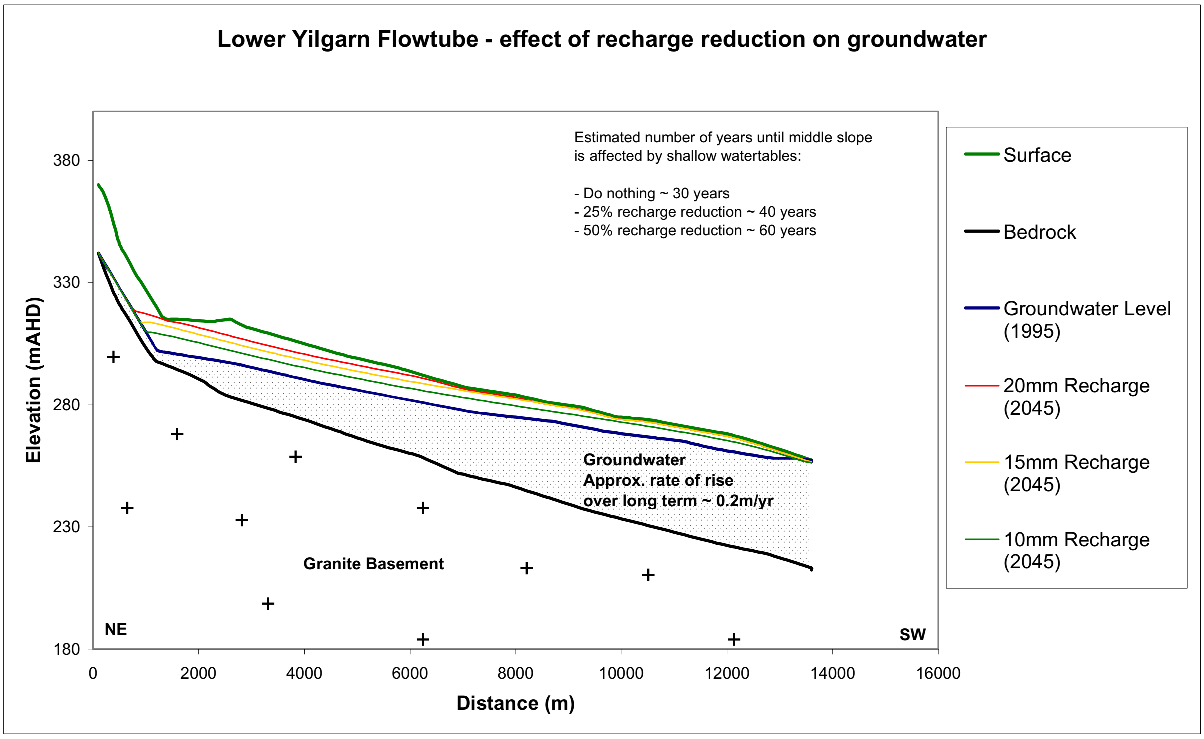


Figure 4.1: Flowtube modelling showing effects of catchment scale recharge reductions.

4.1.2 Managing discharge

4.1.2.1 Deep drainage

Installing drains in soils with low hydraulic conductivity, such as heavy clays, may only impact as little as 10 m of land either side of the drain. However, deep drains can be effective where they intercept more permeable aquifers, that have a hydraulic gradient, even when these are quite thin. These include clay overlying permeable saprolite, sandy sediments and clays with preferred pathways such as sand seams and old root channels.

Field observations indicate that many areas do have ‘coffee rock’ or cemented ironstone layers present at depth which do enhance drainage effects. In such cases the effects of drains can be up to tens or hundreds of metres

Proper design, land degradation potential and safe disposal of water should always be considered before constructing drains. Notices of Intent (NOI) to drain are a legal requirement and recent legislative changes means that preventing environmental harm is in all landholders’ best interests (see also Section 3.5).

Visit the following website for more information on deep drainage:

www.agric.wa.gov.au and search for "deep drain".

4.1.2.2 Groundwater pumping

Groundwater pumping is a valuable tool, particularly for controlling watertables under high value assets. Groundwater pumping to reverse salinisation processes in broadacre agriculture situations, however, is generally considered uneconomic.

Groundwater abstraction by four production bores was modelled (Lewis 2001) and results suggested that groundwater levels could be lowered by up to 3 m in the northern part of Beacon town site. Aquifer pump tests in Kellerberrin achieved draw down at one site up to 340 m away, however draw downs may have been less in other directions (Cattlin 2001).

Qualified hydrogeologists should conduct site investigations to locate production bores, as groundwater systems are complex and variable. As for deep drainage or any other movement of groundwater to address salinity, a NOI needs to be submitted.

For more information on groundwater pumping, visit the following website:

www.agric.wa.gov.au and search for "groundwater pumping".

4.2 Soil management

Table 4.1. Soil management options

Threat	Soil supergroup	Management recommendations
Subsurface compaction 91% of the catchment at risk (789,000 ha)	Deep sand and sandy earths. Coarse-textured sandier soils with less than 5% clay content are most at risk.	– Sandy soils are generally prone to subsoil compaction, but only deeper sands will respond economically to treatments such as deep ripping, as deep ripping the compacted layer will only increase yields if no other root limiting layer is encountered. The use of controlled traffic in conjunction with deep ripping may be useful, as confinement of compaction to tramlines has the benefit of increasing the effectiveness of deep ripping.
Soil structure decline 62% of the catchment at risk (537,000 ha)	Shallow loamy duplex soils, loamy earths and non-cracking clays.	– Soil structure decline can be minimised and reversed by applying gypsum, increasing organic matter (green or brown manuring), blanketing the soil surface with stubble, practising minimum tillage and removing stock during wet periods.
Water repellence 50% of the catchment at risk (433,000 ha)	Deep sands, sandy earths and gravelly soils.	– Water repellence mostly occurs on sandy surfaced soils that have hydrophobic organic matter present. This situation most commonly occurs on the highly productive sands, sandy earths and gravelly soils that are managed under a cereal-legume rotation. – Claying is highly effective on light textured topsoils, containing < 10% clay.
Subsurface acidity 47% of the catchment at risk (407,000 ha)	Deep sands, sandy earths and ironstone gravelly soils, lighter-textured sands and loams. These generally are leached sandy soils with low organic carbon content and little resistance (or buffering capacity) to pH change.	– Testing soil pH in the surface (0–10 cm) and subsurface (10–20 cm) layers is the only accurate way of monitoring acidification. – Liming is the most common method of halting and reversing acidity on productive soils. The total annual lime requirement for the catchment is calculated to range from 30,000 to 50,000 tonnes, based on acidification rates of between 75 and 125 kg lime equivalent/ha/yr for the farming systems and soils (Porter and Miller 1998). – Mount Marshall and Kellerberrin shires are underperforming in lime application rates compared to the catchment as a whole, with lime applications averaging 34% and 52% of the lesser estimated required rate respectively. This can probably be attributed to difficult seasonal and economic conditions and limited extension within Mount Marshall Shire and to a lesser extent within Kellerberrin also. Transport costs to farms in Mount Marshall Shire may also contribute to low lime application rates.

Threat	Soil supergroup	Management recommendations
Wind erosion 47% of the catchment at risk (407,000 ha)	All soils but especially deep sands and sandy earths. Loamy earths, particularly the calcareous loamy earths are wind-blown sediments which are highly prone to wind erosion when cultivated too dry.	– Wind erosion events arise infrequently and usually affect localised areas, but they reduce production at affected sites for several years. Areas of bare loose, dry soil, in higher landscape positions are most at risk (Moore 1998). The most susceptible soil supergroups are deep sands, sandy duplexes and sandy earths on crests and upper slopes. – Wind erosion can be controlled by maintaining at least 50% vegetative cover, planting windbreaks to protect susceptible areas and by stock management. Monitoring of the wind erosion risk of paddocks and adjusting land use practices (e.g. destocking) is essential. Seasonal conditions (such as drought) can make it difficult to maintain ground cover at adequate levels.
Phosphorous export 35% of the catchment at risk (303,000 ha)	Wet and waterlogged soils, sandy and loamy duplex soils situated on valley floors, flow lines and areas susceptible to flooding.	– Fertiliser management is highly effective, particularly for phosphorus with many soils already having moderate to high phosphorus status and not requiring additional applications. – Perennials in buffer strips (only 3 metres wide) along watercourses, which are combined with controlled grazing can reduce nutrient and particulate movement by as much as 90%. – Drainage is generally effective, however, it is dependent on favourable soil properties and hydrological processes, otherwise it may actually increase nutrient export in some cases. Subsurface drainage can reduce nutrient and particulate run-off under suitable environmental conditions, where soils continue to provide nutrient adsorption sites and where leaching is the dominant hydrological pathway.
Waterlogging 33% of the catchment at risk (286,000 ha)	Wet and waterlogged soils, sandy and loamy duplex soils.	– Waterlogging is prevented by employing measures outlined in Section 4.4.

4.3 Farming systems

Susie Murphy-White and Sally Phelan

4.3.1 Leakage calculations

The Leakage Calculator (Raper 2004) for the eastern wheatbelt has been used to calculate the percentage of leakage into the watertable for each water use option on each soil type (Table 4.2). The Leakage Calculator estimates the amount of water flowing beyond the plant roots for each crop on different soil types. The results are discussed in Section 4.3.2.

Table 4.2. Leakage into the watertable for each soil supergroup under each rotation for the eastern wheatbelt

Soil supergroup	Water use options (rotations)	Leakage (% of average annual rainfall) AAR 323 mm
Ironstone gravelly soils (8.5%) Description: Soils containing common to abundant ironstone gravel (S3) Crest and rises Current agriculture: Lupin/wheat (or triticale) Oats/pasture/oats	Bare soil Lupin Cereal Annual pasture Perennial pastures – grasses Serradella Oil mallees Pre-clearing vegetation	19% 2% 2% 2% 0% 2% 0% 0%
Deep sandy duplex (10%) Description: Soils with a sandy surface and a texture contrast at 30-80 cm (S2) Colluvial slopes and valley floors Current agriculture: Lupin/wheat Cereal/volunteer pasture	Bare soil Lupin Cereal Annual pasture Perennial pastures – grasses Lucerne Serradella Oil mallees Saltbush Pre-clearing vegetation	30% 7% 7% 8% 1% 2% 4% 0% 1% 0%
Shallow sandy duplex (6.8%) Description: Soils with a sandy surface and a texture contrast within 30 cm (S4) Colluvial slopes and valley floors Current agriculture: Barley/field peas Cereal/volunteer pasture Canola/wheat	Bare soil Cereal Annual pastures Perennial pastures – grasses Lucerne Serradella Oil mallees Saltbush Pre-clearing vegetation	12% 1% 1% 1% 1% 1% 0% 0% 0%

Soil supergroup	Water use options (rotations)	Leakage (% of average annual rainfall) AAR 323 mm
Deep sands (7.9%) Description: Sands > 80 cm deep with a sand to clayey sand texture (S2) Sandplains, spillway sands and depressions in lateritic terrain Current agriculture: Lupins/serradella	Bare soil Lupin Cereal Annual pastures Serradella Perennial pastures – grasses Lucerne Oil mallee Pre-clearing vegetation	30% 7% 7% 8% 4% 1% 2% 0% 0%
Sandy earths (18.9%) Description: Soils with sandy surface and grading to loam by 80 cm (S1) Sandplains, colluvial and alluvial sediments Current agriculture: Serradella/wheat/lupins	Bare soil Lupin Cereal Annual pastures Serradella Perennial pastures – grasses Oil mallees Pre-clearing vegetation	26% 7% 7% 9% 5% 4% 0% 0%
Shallow loamy duplex (21.3%) Description: Soils with a loamy topsoil and a texture contrast within 30cm (S4) Crest, side slopes and valley floors Current agriculture: Cereals/lupin/canola	Bare soil Lupin Cereal Annual pastures Perennial pastures Oil mallee Saltbush Pre-clearing vegetation	12% 1% 1% 1% 1% 0% 0% 0%
Loamy earths (12.1%) Description: Soils with a loamy profile or may grade to clay by 80 cm (S5) Wind-blown lake sediments and colluvium on lower slopes Current agriculture: Wheat/grain legume/medics Canola/cereal/pasture	Bare soil Cereal Annual pastures Perennial pastures – grasses Lucerne Oil mallee Saltbush Pre-clearing vegetation	9% 1% 1% 0% 0% 0% 0% 0%
Clays (3.3%) Description: Hard or self-mulching cracking clay that strongly cracks when dry (S6) Red/brown or grey non-cracking clay (S6) Valley floors Current agriculture: Wheat/grain legume/field pea/lentil	Bare soil Cereal Annual pastures Perennial pastures Saltbush Pre-clearing vegetation	11% 2% 3% 2% 0% 0%

High leakage – greater than 5 per cent of MAR or greater than 10 per cent of AAR for permeable soils.
Moderate leakage – 2.5-5 per cent of MAR or 5-10 per cent of AAR for permeable soils.
Low leakage – less than 2.5 per cent of MAR or less than 5 per cent of AAR for permeable soils.

4.3.2 Managing leakage

4.3.2.1 Annual crop and pastures

Low leakage rates of 1-2 per cent on the ironstone gravelly sands, shallow duplexes, loamy earths and clay soils can be achieved by annual crop and pasture rotations that use best practice agronomy. Annual crops such as wheat, barley, and lupins use more water than traditional pastures (medics, subterranean clovers, clovers and volunteer pastures). Therefore, continuous cropping rotations will have less leakage than the rotations dominated by poorly established pastures.

Moderate leakage rates of 7-9 per cent on deep sandy duplexes, deep sands and sandy earths contribute 22-30 mm/year of the average annual rainfall when crop and pasture rotations use best practice agronomy. To improve water usage on these soils deep rooted annual legume pastures such as serradella should be used and will decrease the leakage rate by half (4 per cent) on good sandplain soils. Perennial pastures including lucerne and perennial grasses can reduce leakage to 1-4 per cent of average annual rainfall.

Bare soil in any rotation will have a high leakage rate and is conducive for rising watertables.

4.3.2.2 Perennial pastures

Perennial pastures have the potential to use water year-round (if growing well and are not dormant), are generally deeper rooted than annuals and are better at drying the soil profile. Lucerne is one perennial that may be suitable on deep sandy duplexes, shallow sandy duplexes and deep sands. Lucerne can be incorporated into the farming system by phase cropping. This usually does not involve many changes to farming practices. Establishment of lucerne can prove difficult in years when average spring and summer rains are not received. If an even ground coverage and good density of plants (Kingwell 2003) is not achieved then the site would be susceptible to increased leakage and wind and water erosion.

4.3.2.3 Integrating woody perennials

Woody perennials use more water than perennial pastures and result in 0-1 per cent leakage. They can be integrated into the farming landscape on soils that are difficult to crop or produce marginal economic return. The options for woody perennials include: saltbush, tagasaste, oil mallees, sandalwood and speciality timbers (Table 4.6). Apart from the options that can be grazed, only niche markets exists for other woody perennials.

4.3.3 Saltland pastures in the farming system

Most farms will have an excess of feed for grazing animals in spring, but a feed deficiency in autumn. Providing feed supplements of grain or hay normally covers this deficiency. Farms with saltland pastures may be more profitable because the autumn feed gap is filled using a feed resource grown on wasteland and the reserved grain/hay is sold.

Because saltbush is high in protein but low in energy, either supplementation or good, alternative, understorey growth is needed for sheep to maintain condition. In highly saline soils where understorey growth is not possible, supplementation is needed and should be in the form of barley grain or a high quality hay.

For less saline soils where understorey growth is possible, the following species can be successful in low rainfall areas, given the right site, soil type and conditions are selected.

Table 4.3. Suitable saltland pasture species

Species	Salinity indicator species/landscape position	Suitable saline soil type	Benefits
Old man saltbush	Above samphire zone	Any	Deep rooted, high water user.
River saltbush	Above samphire zone	Any	Highly palatable, semi-prostrate plant.
Wavy leaf saltbush	Above samphire zone	Any	Easily established through direct seeding.
Small leaf bluebush	Barley grass, not waterlogged	Morrel soils, loams	Natural coloniser. Easily established by laying in-seed branches on area.
Puccinellia*	Barley grass, bare saline soils	Sandy duplexes, loams, not hard-setting or dispersive soils	Perennial, highly water-logging and salt tolerant.
Tall wheat grass*	Barley grass, ryegrass	Sandy duplexes, loams, not hard-setting or dispersive soils	Green all year, highly salt tolerant, very palatable.
Frontier balansa clover	Waterlogged, mildly saline soils	Not hard-setting or dispersive soils	Early maturing variety. High energy feed in summer.

* In low rainfall areas, these species should be planted in sites with subsurface moisture.

4.4 Surface water management

Harry Lauk and Ian Wardell-Johnson

4.4.1 Priority areas

Surface water management should focus on the following:

- waterlogging on the slopes of the sandy/loamy duplex soils;
- waterlogging on valley floors;
- waterlogging below smaller hillside seep areas;
- hillside seeps and flood prone areas in wet years;
- proper maintenance of existing surface water control earthworks;
- maximising on farm water supplies in below average rainfall years;
- controlling water erosion on slopes from 3-10 per cent;
- appropriate design of earthworks; and
- notification of drainage and pumping proposals.

4.4.2 Surface water control

The amount of surface water run-off from each of the four main soil supergroups is affected by slope and landscape position (for example: valley floors, foot slope, upper slope and crests). A quick assessment of these slope classes can be made using ortho-photos overlain with 2 m contours. Earthworks can then be planned, considering soil type, to help reduce waterlogging (Table 4.4).

Higher slopes (3-10 per cent) are mainly present in the southern areas. In the northern half of the catchment slopes are generally less than 3 per cent.

Table 4.4. Possible earthworks for slope classes and landscape elements

Slope class (%)	Landscape element	Suitable earthworks
0-1% slope (51% **of catchment**)	Valley floors/lower footslopes	Shallow relief drains Levee and levied waterways
1-3% slope (45% **of catchment**)	Long slopes/footslopes	Grade bank Conventional seepage interceptor drains Levee and levied waterways Diversion bank Broad-based bank (not less than 2%)
3-5% slope (3% **of catchment**)	Mid-slopes/minor upperslopes	Grade bank Seepage interceptor drains Levee and levied waterways Diversion bank Broad-based bank
5-10% slope (less 1% **of catchment**)	Upperslopes	Grade bank Level/adsorption banks directly below steep slopes of mallet hills Levee and levied waterways Diversion bank
> 10% slope (less 1% **of catchment**)	Steep slopes/mallet hills/rock outcrop	Use conservation land management practices Absorption banks if erosion a problem

4.4.3 Recommended surface water earthwork options

Grade banks, absorption banks, reverse bank interceptors drains and waterways may be used on slopes between 1 per cent and 10 per cent depending on the site. The most suitable soils for these earthworks are loams, sandy surfaced duplex and clays. Shallow surface drains may be used on slopes with less than 1 per cent slope. The most suitable soils for shallow drains are duplex soils and clay soils.

The range of appropriate engineering options for the four main soil supergroups are described in Table 4.5 and slope class distribution is shown in Figure 4.2.

Table 4.5. Recommendations for surface water control

Soil supergroups	Management issues	Appropriate earthworks
Shallow loamy duplex (21% of catchment)	Surface water erosion may be an issue on steeper slopes. Waterlogging may also be a problem in wet years.	Grade banks to intercept excess surface water Conventional interceptor drains if duplex soils
Sandy earths (19% of catchment)	Water management only a problem in a wetter than average year – waterlogging main issue.	Grade bank systems to stable waterway Levee waterways
Loamy earths (12% of catchment)	Surface water erosion may be an issue on steeper slopes. Waterlogging may also be a problem in wet years.	Grade banks to intercept excess surface water Conventional interceptor drains if duplex soils
Deep sandy duplex (10% of catchment)	Usually no surface water issues.	Not required Usually no surface water issues
Deep sands (8% of catchment)	Usually no surface water issues.	Not required Usually no surface water issues
Ironstone gravelly soils (8% of catchment)	Usually no surface water issues unless on breakaways.	Grade or level banks if erosion present
Shallow sandy duplex (7% of catchment)	Surface water erosion may be issue on steeper slopes. Waterlogging may also be problem in wet years.	Grade banks to intercept excess surface water Conventional interceptor drains if duplex soils
Wet or waterlogged soils or clay (7% of catchment)	Water erosion. Flooding on valley flats. Waterlogging.	Grade bank systems Shallow relief drains/w-drains Conventional seepage interceptor drains Deep drains in limited areas

4.4.4 Earthworks for water conservation, supply and management

Earthworks, including grade banks, diversion banks, grassed waterways, roaded catchments and dams, are the primary method of water conservation and storage. The works described earlier in this section can often be utilised to divert water into storage. However, rarely are earthen storage structures 100 per cent efficient, so they usually contribute to recharge via preferred pathways and matrix flow, particularly given the significant hydraulic gradient under such structures. Design is therefore important to maximise storage efficiency and to minimise recharge.

Roaded catchments are designed to capture rainwater and provide an efficient method of increasing run-off into farm dams. A well constructed and maintained roaded catchment can start to shed water after only 4–6 mm rainfall, whereas grade banks will not. However, poorly maintained roaded catchments can require up to 10–15 mm of rainfall to produce run-off. From survey information it has been shown that there are very few roaded catchments on farms in the catchment.

4.4.4.1 Other surface water resources

According to Mt Marshall Water Assets 2003 there are many surface water resources such as rock outcrops, rocky hills and soaks that have potential as water collecting sites within this particular shire (Trustum 2003). The shire has a number of dams that are resources for the community and are not linked to the scheme water system. Other shires could have similar resources that have potential water collecting sites.

4.5 Native vegetation

Sally Phelan

Most remnants are small, isolated and lack connectivity to other remnants. They may also be at risk due to salinity, weed invasion, grazing and spray drift from agricultural activities. The following management options may help to enhance remnant condition and protect biodiversity values.

- **Strategic revegetation.** Revegetation with the use of seedlings can reduce recharge and the effects of salinity and waterlogging, whilst increasing the area of native vegetation. Planting corridors or revegetation near existing remnants can reduce edge effects (such as spray drift and weed invasion) in small and isolated remnants. Revegetation is most effective for salinity management when used in small problem areas such as sandplain seeps. For biodiversity values, direct seeding gives the most natural effect for a functioning ecosystem, but may be difficult in low rainfall areas.

- **Corridors.** Wildlife corridors protect and connect existing remnant vegetation patches using paddock boundaries, drainage lines and shelter belts. Corridor effectiveness depends largely on the width of the corridor itself. A corridor should be planted as wide as is practicable to reduce edge effects (Lambeck 1999).

- **Fencing remnants.** Excluding stock from remnants allows the understorey to regenerate and reduces the introduction of weeds which out-compete native species by fast germination. Alternative shelter belts for stock protection can be established by planting fast growing species in areas where stock regularly camp.

- **Weed control.** The maintenance of intact native vegetation canopies and the maintenance of a low nutrient system encourages weed resistance in remnant vegetation. The use of herbicides in remnants must be treated with caution. Grass selective herbicides can be applied after weed germination, but before the germination of native grasses. Often continuous management is required to keep weeds at a minimum.

- **Spray drift control.** Chemical use from normal farm operations can damage remnant vegetation, generally from spray drift effects. Spraying in calm conditions can reduce this effect.

4.6 Commercial vegetation

Sally Phelan

Commercial trees or fodder shrubs can not only provide an economic return, but may also help to reduce recharge and the effects of rising watertables and salinity. Often tree crops or fodder shrubs are planted in problem soils that are not productive, such as tagasaste in deep sands. However, water using trees or shrubs can be useful as a preventative measure, when planted on low lying areas that are at risk of salinity in the future. Planting in an alley formation means that either crops or pasture can be planted in the inter-row. This is applicable in all parts of the landscape. The following table lists suitable tree crops/fodder species.

Table 4.6. Commercial species options

Species	Soil group	Benefits/limitations
Tagasaste	Deep sands, deep sandy duplexes, sandy earths	Can be alley farmed with serradella on problem sands. Need to be slashed for sheep grazing.
Oil mallees	Several species suited to different all types except saline soils	Market relies on the establishment of processing plants. A forecast return of $15/tonne, or $600/ha every two years.
Broombush	Various soil types including saline and waterlogged soils	Small market for use as brushwood fencing. Currently research into broombush as a ‘salt-tolerant oil mallee’.
Saltbush	Saline and wet or waterlogged soils	Fills autumn feed gap using land that would otherwise not be utilised. Environmental benefits. May take several years after establishment to see economic returns.

5. CONCLUSIONS

- A level of intervention is necessary to help buy time in regards to rising watertables. Increased use of perennials across the landscape will be essential and a practical aim would be to attempt to achieve a 25 per cent reduction in recharge. Using lucerne is an option but performance in dry years will need to be considered. Oil mallees and tagasaste may be potentially viable commercial woody perennial species that could be utilised.

- Valley floors are a resource and can be managed for grazing, using a mixture of salt tolerant perennial species and annual pastures.

- Surface water problems can be managed across the majority of the catchment by using grade banks. Deep drainage is an option for groundwater management, where permeable aquifers exist. Such drainage should be properly engineered and the Commissioner for Soil and Land Conservation notified before any work is carried out.

- Remnant vegetation has a role in contributing to water usage and biodiversity and can be protected by buffering with commercial perennial species. Alley plantings are considered the most suitable approach, particularly for low lying areas.

- Continuous cropping on ironstone gravelly sands, shallow duplexes, loamy earths and clay soils may prove more effective than rotations that involve pastures to manage rainfall leakage.

- Deep rooted annual legume pastures such as serradella and perennial pastures including lucerne and perennial grasses should be used on deep sandy duplexes, deep sands and sandy earths to improve water usage.

- Soil acidity, soil structure decline and soil compaction have been highlighted by local land managers as three priority soil condition issues. Monitoring for soil pH is essential and this should be coupled with ongoing lime application. Liming rates need to be looked at to ensure that sufficient lime is being applied. Soil structure decline can be managed utilising practices that retain stubble and help increase organic matter (green/brown manuring is a viable option). Stock management is essential during wet periods to manage soil compaction, deep ripping is viable on deep sands and controlled traffic should be considered.

- Fresh or stock quality groundwater resources are very limited. Landholders seeking such water should target drill sites that have at least 2–6 m depth of sand/gravel present at the surface, are not located near major drainage lines or are not in upland areas that converge ground/surface water.

6. REFERENCES

Australian Bureau of Statistics (1999). Agstats data base. ABS Canberra.

BankWest (2002). BankWest Benchmarks 2001-2002 Season. BankWest Perth.

Burt, E. (2002). Mt Marshall, Trayning, Kellerberrin, Merredin and Bruce Rock Shire economic overviews. Department of Agriculture, Merredin.

Cattlin, T. (2001). Groundwater study of the Kellerberrin townsite. Resource Management Technical Report 210, Department of Agriculture WA.

Chin, R.J. (1986). 1:250,000 Geological Series – explanatory notes. Kellerberrin Sheet SH50-15 International Index. Geological Survey of Western Australia 1986.

Ferdowsian, R., Pannell, D.J., McCaron, C., Ryder, A. and Crossing, L. (2001). Explaining groundwater hydrographs: Separating atypical rainfall events from time trends. *Australian Journal of Soil Research* 39: 861-875.

George, R. and Frantom, P.W.C. (1987). Preliminary groundwater and salinity investigations in the eastern wheatbelt: Welbungin and Beacon River Catchments. Resource Management Technical Report 90, Department of Agriculture WA.

George, R.J. and Kingwell, R. (2003). Salinity investment framework: agricultural land and infrastructure. Analysis by the Department of Agriculture. Draft: January 22, 2003.

Ghauri, S.R. (2004). Groundwater trends in the Central Agricultural Region. Resource Management Technical Report, Department of Agriculture, March 2004. ISSN 1039-7205.

Kingwell, R. (2003). Economic evaluation of salinity management options in cropping regions of Australia. GRDC and National Dryland Salinity Program.

Lambeck, R.J. (1999). Landscape planning for biodiversity conservation in agricultural regions. Biodiversity Technical Paper No. 2, Department of Environment and Heritage, Canberra.

Laws, A.T. (1989). Hydrogeological investigations in the Merredin Catchment proposed drilling program. Geological Survey of Western Australia 1988/9.

Laws, A.T. (1981). Report on groundwater prospects – Merredin – South Merredin Primary School. Geological Survey of Western Australia 1981.

Lewis, F. (2001). Groundwater study of the Beacon townsite. Resource Management Technical Report 204, August 2001, Department of Agriculture WA.

Moore, G. (1998). Soilguide. A handbook for understanding and managing agricultural soils. Agriculture Western Australia Bulletin No. 4343.

Mulcahy, M.J. (1967). Landscapes, laterites and soils in southwestern Australia. *In:* Landform studies from Australia and New Guinea. (Eds: J.N. Jennings and J.A. Mabbutt) ANU press, Canberra.

Parsons, A. (2003). Bringing back the birds: Landscape planning for nature conservation in Wallatin Creek Catchment. CSIRO, Perth.

Porter, W.M. and Miller, A. (1998). Lime use targets for Western Australia. *In:* Western Australia soil acidity research and development 1998. Bulletin No. 4506, WA Department of Agriculture, pp 12–15.

Raper, P. (2004). Eastern wheatbelt Leakage Calculator. Department of Agriculture.

Sharafi, S. (2004). Refinement to landmonitor methodology to define valley floors. Research Officer, Dryland Research Institute, Department of Agriculture, Merredin, Western Australia. Unpublished.

Schoknecht, N.R. (2002). Soil groups of Western Australia. Department of Agriculture Resource Management Technical Report 246.

Trustum, K. (2003). Mount Marshall water assets 2003. Shire of Mount Marshall Assets Document November 2003. Western Australia.

WA Department of Agriculture (2003). Natural resource management issues in the agricultural zone of Western Australia. Focus: Avon River Basin. Draft Technical Report.

7. APPENDICES

A1. Land system and subsystem descriptions

Map unit	Map unit name	Description
258Be	Beacon System	Valley floors around the salt lakes. Calcareous loamy earths, red loamy and sandy earths, minor red sandy and loamy duplexes and clays. Salmon gum-gimlet-wandoo-York gum woodland.
258BeCL	258Be Cleary Subsystem	Valley floors and lower slopes, in the northern zone of Ancient Drainage, with calcareous loamy earth, red shallow sand and alkaline red loamy duplex (deep and shallow). Salmon gum-gimlet woodland.
258BeKU	258Be Kununoppin Subsystem	Valley floors and lower slopes, in the central zone of Ancient Drainage, with calcareous loamy earth. Morrell-salmon gum woodland.
258BeMU	258Be Mukinbudin Subsystem	Valley floors, in the central zone of Ancient Drainage, with calcareous loamy earth and alkaline red loamy duplex (mostly shallow). Woodland.
258Br	Bonnie Rock System	Gently undulating sandplain and associated slopes and minor rock outcrop. Acid yellow and yellow sandy earths, yellow deep sands, red sandy earths, loamy gravels and minor loams, duplexes and rock outcrops. Heath and shrubland, salmon gum woodland.
258BrKO	Koorda Subsystem	Gently undulating sandplain, in the central zone of Ancient Drainage, with yellow sandy earth (often acid) and yellow deep sand. Heath and shrubland.
258BrKW	258Br Kwelkan Subsystem	Undulating granitic low hills, in the central zone of Ancient Drainage, with bare rock, deep sandy duplex (grey and red), shallow sand (red and yellow/brown) and red loamy duplex. York gum-jam woodland.
258BrNE	258Br Nembudding Subsystem	Rises and low hills, in the northern zone of Ancient Drainage, with alkaline red loamy duplex (mostly shallow) and yellow sandy earth. Mallee scrub and woodland.
258BrWI	258Br Wialki Subsystem	Undulating rises, in the central zone of Ancient Drainage, with red shallow sand and alkaline red loamy duplex (mostly shallow). Salmon gum woodland.
258Kb	Kellerberrin System	Valley floors, in the central zone of Ancient Drainage, with alkaline red shallow loamy duplex, alkaline grey sandy duplexes mainly in branch valleys (shallow and deep), calcareous loamy earth and hard cracking clay. Salmon gum-gimlet-wandoo.

Map unit	Map unit name	Description
258Kb_1	Kellerberrin 1 Subsystem	Alluvial deposits differentiated as grey sandy duplexes (often alkaline-sodic) and loamy earths (red-brown and calcareous).
258Kb_1ns	Kellerberrin 1 non-saline phase	Broad, flat valleys of the central and eastern wheatbelt containing sand over clay soils.
258Kb_2	Kellerberrin 2 Subsystem	Various aeolian and alluvial deposits adjacent to playa lakes.
258Kb_2ns	Kellerberrin 2 non-saline phase	Un-salinised broad, flat valleys of the central and eastern wheatbelt containing heavy red and grey soils.
258Kb_2sal	Kellerberrin 2 saline phase	Saline areas within broad, flat valleys of the eastern wheatbelt containing red and grey mottled clayey soils.
258Kb_2sl	Kellerberrin 2 salt lake phase	Salt lakes within broad, flat valleys of the eastern wheatbelt containing heavy red and grey soils.
258Kb_3	Kellerberrin 3 Subsystem	Saline lakes.
258Kb_3ns	Kellerberrin 3 non-saline phase	Areas of reddish, powdery surfaced ‘Morrel soils’, often adjacent to salt lakes.
258Kb_3sal	Kellerberrin 3 saline phase	Saline areas with reddish, powdery surfaced ‘Morrel soils’ adjacent to salt lakes.
258Kb_3sl	Kellerberrin 3 salt lake phase	Salt lakes and associated aeolian deposits blanketing broad valley floors in the north-eastern wheatbelt, in the northern zone of Ancient Drainage.
258KbBE	258Kb Belka Subsystem	Broad, flat valleys of the central and eastern wheatbelt containing sand over clay soils.
258KbHH	258Kb Hines Hill Subsystem	Flat, or gently sloping areas on the lee side of the main salt lake channels. Baandee depositional surface. Calcareous loamy earth soils.
258KbKU	258Kb Kununoppin Subsystem	Valley floors and lower slopes, in the central zone of Ancient Drainage, with calcareous loamy earth. Morrell-salmon gum woodland.
258KbME	258Kb Merredin Subsystem	Broad, flat valleys of the eastern wheatbelt containing heavy, red and grey soils.
258KbMU	258Kb Mukinbudin Subsystem	Valley floors, in the central zone of Ancient Drainage, with calcareous loamy earth and alkaline red loamy duplex (mostly shallow). Woodland.
258KbNA	258Kb Nangeenan Subsystem	Areas of reddish, powdery surfaced ‘morrel soils’ that often occur adjacent to salt lakes.
258KbTR	258Kb Trayning Subsystem	Valley floors, in the central zone of Ancient Drainage, with alkaline red shallow loamy duplex, alkaline grey sandy duplex (shallow and deep), calcareous loamy earth and hard cracking clay. Salmon gum-gimlet-wandoo-York gum woodland.

Map unit	Map unit name	Description
258Ky	Kwolyin System	Gently undulating granitic terrain of the Kellerberrin batholith with large outcrops of granite, dominated by duplex soils with minor sandplain. York gum/salmon gum woodlands with minor wandoo, jam, sheoak and heath.
258Ky_1	Kwolyin 1 Subsystem	Crests and upper slopes on sandplain with weakly expressed, weakly indurated breakaways and colluvial back slopes, comprising gravelly yellow sands, earths and gravels under tammar and kwongan heath.
258Ky_2	Kwolyin 2 Subsystem	Very smoothly undulating sandy aeolian deposits on uplands located directly south-east of valley sources, comprising deep yellow sands and earths with gravels forming from recent lateritisation, typically vegetated by banksia woodland.
258Ky_2a	Kwolyin 2 aeolian phase	Very smoothly undulating calcareous aeolian deposits on uplands located directly south-east of valley sources, comprising calcareous loams overprinting various substrates, typically vegetated by morrel, salmon gum and boree.
258Ky_3	Kwolyin 3 Subsystem	Irregularly undulating rocky outcrops and the gently undulating slopes of colluvial mantles surrounding the area underlain by the Kellerberrin batholith.
258Ky_3d	Kwolyin 3 dolerite phase	Red and brown loamy and clayey soils on dolerite and diorite dykes in irregularly undulating uplands of the Kellerberrin batholith.
258Ky_3g	Kwolyin 3 granite phase	Small rock outcrop surrounded by shallow sandy skeletal soils and duplex soils forming from siliceous granite in irregularly undulating uplands of the Kellerberrin batholith.
258Ky_3q	Kwolyin 3 quartz phase	Shallow sandy and rocky skeletal soils and duplex soils with poorly structured amorphous ‘B’ horizons forming from quartzite ridges in irregularly undulating uplands of the Kellerberrin batholith.
258Ky_3r	Kwolyin 3 rock phase	Rock outcrops and shallow skeletal soils in irregularly undulating uplands of the Kellerberrin batholith.
258Ky_3sal	Kwolyin 3 saline phase	Narrow saline and waterlogged drainage lines, possibly expressing as a result of restrictive layer such as bedrock highs.
258Ky_3u	Kwolyin 3 undifferentiated phase	Shallow and deep sandy and loamy duplex soils forming on colluvial surfaces in smoothly undulating uplands of the Kellerberrin batholith.
258KyBR	258Ky Booraan Subsystem	Hill slopes predominantly containing hardsetting, grey to brownish sandy loam over clay soils.
258KyCG	258Ky Collgar Subsystem	Gentle, lower slopes containing sandy surfaced duplex or ‘mallee soils’.

Map unit	Map unit name	Description
258KyDB	258Ky Danberrin Subsystem	Areas of rocky, red and greyish brown loamy sands and sandy loams formed from freshly exposed bedrock. Rock outcrop is common.
258KyKW	258Ky Kwelkan Subsystem	Undulating granitic low hills, in the central zone of Ancient Drainage, with bare rock, deep sandy duplex (grey and red), shallow sand (red and yellow/brown) and red loamy duplex. York gum-jam woodland.
258KyNE	258Ky Nembudding Subsystem	Rises and low hills, in the northern zone of Ancient Drainage, with alkaline red loamy duplex (mostly shallow) and yellow sandy earth. Mallee scrub and woodland.
258KyR3	258Ky Steep Rocky Hills 3 Subsystem	Areas of bare rock and steep rocky hills with minimal soil development.
258KyUL	258Ky Ulva Subsystem	Yellow sandplain and gravel plain of the eastern wheatbelt. This unit contains small areas of pale sand.
258KyYE	258Ky Yelbeni Subsystem	Gently undulating sandplain, in the central zone of Ancient Drainage, with yellow sandy earth (occasionally acid), yellow deep sand, gravel and pale deep sand. Heath, shrubland and mallee scrub.
258KyYT	258Ky Yetelling Subsystem	Undulating greenstone low hills, in the central zone of Ancient Drainage, with red loamy earth and hard cracking clay. Mallee scrub and salmon gum woodland.
258Ta	Tandegin System	Sandplain dominated interfluves with weakly indurated lateritised crests and upper slopes and long colluvial yellow sandplain upper to lower slopes. Unlateritised surfaces dominated by sodic and alkaline duplex soils.
258Ta_1	Tandegin 1 Subsystem	Crests and upper slopes in sandplain, with weakly expressed and indurated breakaways and colluvial back slopes comprising gravelly yellow sands, earths and gravels with tammar and kwongan heath.
258Ta_2	Tandegin 2 Subsystem	Very smoothly undulating sandy aeolian deposits on uplands located directly south-east of valley sources, comprising deep yellow sands and earths with gravels forming from recent lateritisation, typically vegetated by banksia woodland.
258Ta_2a	Tandegin 2 aeolian phase	Very smoothly undulating calcareous aeolian deposits on uplands located directly south-east of valley sources, comprising calcareous loams overprinting various substrates, typically vegetated by morrel, salmon gum and boree.
258Ta_3	Tandegin 3 Subsystem	Unlateritised gently undulating terrain of fresh rock (irregularly undulating) and colluvial surfaces (smoothly undulating) with alkaline duplexes and loams and eucalyptus woodland and low mallee woodland in the eastern wheatbelt.

Map unit	Map unit name	Description
258Ta_3d	Tandegin 3 dolerite phase	Red and brown loamy and clayey soils on dolerite and diorite dykes in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Ta_3g	Tandegin 3 granite phase	Small areas of rock outcrop surrounded by shallow sandy skeletal soils and duplex soils (often sodic) forming from siliceous granite in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Ta_3ge	Tandegin 3 granodiorite phase	Red and brown loamy, clayey and minor duplex soils on granodiorite, granite and minor dolerite dykes, in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Ta_3q	Tandegin 3 quartz phase	Shallow sandy and rocky skeletal soils and duplex soils with poorly structured amorphous ‘B’ horizons forming from quartzite ridges in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Ta_3r	Tandegin 3 rock outcrop phase	Rock outcrops and shallow soils supporting acacia and sheoak woodlands in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Ta_3u	Tandegin 3 undifferentiated phase	Smoothly undulating mid and lower (and rarely upper) colluvial slopes forming mainly sodic and alkaline duplex soils in the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258TaBR	258Ta Booraan Subsystem	Hill slopes predominantly containing hardsetting, grey to brownish sandy loam over clay soils.
258TaCG	258Ta Collgar Subsystem	Gentle, lower slopes containing sandy surfaced duplex or ‘mallee soils’.
258TaDB	258Ta Danberrin Subsystem	Areas of rocky, red and greyish brown loamy sands and sandy loams formed from freshly exposed bedrock. Rock outcrop is common.
258TaKW	258Ta Kwelkan Subsystem	Undulating granitic low hills, in the central zone of Ancient Drainage, with bare rock, deep sandy duplex (grey and red), shallow sand (red and yellow/brown) and red loamy duplex. York gum-jam woodland.
258TaNE	258Ta Nembudding Subsystem	Rises and low hills, in the northern zone of Ancient Drainage, with alkaline red loamy duplex (mostly shallow) and yellow sandy earth. Mallee scrub and woodland.
258TaNU	258Ta Nungarin Subsystem	Gently undulating plains, in the central zone of Ancient Drainage, with grey sandy duplex (shallow and deep) and grey shallow loamy duplex (often alkaline). Salmon gum-gimlet-wandoo woodland and mallee scrub.
258TaR3	258Ta Steep Rocky Hills 3 Subsystem	Areas of bare rock and steep rocky hills with minimal soil development.

Map unit	Map unit name	Description
258TaUL	258Ta Ulva Subsystem	Yellow sandplain and gravel plain of the eastern wheatbelt. This unit contains small areas of pale sand.
258TaYE	258Ta Yelbeni Subsystem	Gently undulating sandplain, in the central zone of Ancient Drainage, with yellow sandy earth (occasionally acid), yellow deep sand, gravel and pale deep sand. Heath, shrubland and mallee scrub.
258Wa	Wallambin System	Salt lake chains, in the central zone of Ancient Drainage, with salt lake soil and calcareous loamy earth. Mallee, morrel woodland and saltbush-bluebush-samphire flats.
258Wa_1	Wallambin 1 Subsystem	Saline playas, often wet.
258Wa_1sl	Wallambin 1 salt lakes phase	Salt lakes.
258Wa_2	Wallambin 2 Subsystem	Salt lake chains and surrounding dunes and flats.
258WaBA	Wallambin Baandee Subsystem	Salt lakes, channels, flats and associated dunes.
258WaBAlf	Baandee lake fringe phase	Lunettes and small saline drainage courses within salt lake chains of the north-eastern wheatbelt.
258WaBAsl	Baandee salt lake phase	Salt lakes and deflationary features in north-eastern wheatbelt valleys.
258WaBAst	Stirling Subsystem	Fringe zones on either side of the main salt lake channels with isolated salt lakes, gypsum dunes and lunettes of sand, silt or clay. Baandee erosional and depositional surfaces.
258Wd	Wadderin System	Gently undulating rises on mixed gneissic terrain largely stripped of lateritic mantles with sandy duplexes and some sands and gravels, vegetated by mallee and kwongan heath.
258Wd_1	Wadderin 1 Subsystem	Gently undulating rises with weakly expressed breakaways. Shallow and loamy gravels and long gentle back slopes comprising yellow sands and sandy earths under kwongan heath, acacia and allocasuarina woodland.
258Wd_2	Wadderin 2 Subsystem	Aeolian map units need to be better defined using profile descriptions, however, not enough point observations exist.
258Wd_2a	Wadderin 2 aeolian phase	Uniform convex to linear gently undulating uplands between Narembeen and Bruce Rock with calcareous aeolian deposits overprinting various substrates and forming red to brown calcareous loams vegetated by morrel/salmon gum woodlands.

Map unit	Map unit name	Description
258Wd_3	Wadderin 3 Subsystem	Gently undulating colluvial slopes with some irregularly undulating shallow regolith with rock outcrops, comprising brown to grey duplexes and red to brown loamy earths, loamy duplexes and clays, vegetated by mallee and salmon gum/gimlet woodland.
258Wd_3d	Wadderin 3 dolerite phase	Irregularly undulating uplands between Narembeen and Bruce Rock where dolerite and diorite dykes outcrop, forming red to brown clayey, well structured, usually calcareous soils vegetated by York gum and jam woodlands with some wandoo and gimlet.
258Wd_3g	Wadderin 3 granite phase	Irregularly undulating uplands between Narembeen and Bruce Rock where siliceous granites outcrop, forming shallow and deep duplexes that are usually dispersed and often calcareous, and minor gritty sands, vegetated by York/jam/wandoo woodland.
258Wd_3ge	Wadderin 3 granodiorite phase	Irregularly undulating uplands between Narembeen and Bruce Rock where biotite rich granites and gneiss outcrop. Red to brown duplexes and loamy earths with calcareous and clayey phases vegetated by York/jam and minor gimlet/wandoo woodland.
258Wd_3q	Wadderin 3 quartz phase	Shallow sandy and rocky skeletal soils, and duplex soils with poorly structured amorphous 'B' horizons forming from quartzite ridges in irregularly undulating uplands of the eastern wheatbelt around Bruce Rock, Muntadgin and Merredin.
258Wd_3r	Wadderin 3 rock phase	Rock outcrop and minor deep gritty sands and red/brown loams within irregular terrain between Narembeen and Bruce Rock, vegetated by *Acacia acuminata*, *A. lasiocalyx*, *Allocasuarina heugeliana* woodlands.
258Wd_3u	Wadderin 3 undifferentiated phase	Colluvial and residual mantle, gently undulating slopes, with acid to neutral duplexes under mallee on upper to mid slopes and mallee, gimlet and salmon gum vegetation on neutral to alkaline duplexes and clays in lower positions.
258Wo_2	Bendering 2 Subsystem	Gently undulating interfluves with weakly expressed breakaways and long gentle back slopes. Yellowish lateritic gravel flanked by earthy yellow sandplain that tends to be dominated by gravel.

A2. Contacts

The most important source of agricultural resource management information is: www.agric.wa.gov.au

Natural resource management information can also be found at: www.avonicm.org.au

Table A2.1. Contacts list

Area	Contact name	Contact details
Farming systems	Susie Murphy-White	Department of Agriculture, Merredin Phone: 9081 3111; Fax: 9041 1138 E-mail: smurphywhite@agric.wa.gov.au
Hydrology	Shahzad Ghauri	Department of Agriculture, Northam Phone: 9690 2102; Fax: 9622 1902 E-mail: sghauri@agric.wa.gov.au
Surface water management and drainage	Harry Lauk	Department of Agriculture, Northam Phone: 9690 2162; Fax: 9622 1902 E-mail: hlauk@agric.wa.gov.au
Remnant vegetation/ revegetation	Sally Phelan	Department of Agriculture, Lake Grace Phone: 9865 1205; Fax: 9865 1282 E-mail: sphelan@agric.wa.gov.au