Moore Catchment Council Inc.

Local Area Plan for the Control of Rising Groundwater and Salinity in the Koojan-Gillingarra Region

Version 5.0 **August, 2008**

Local Area Plan for the Control of Rising Groundwater and Salinity

in the Koojan-Gillingarra Region

August, 2008

Prepared by *Viv Read & Associates*

for the Moore Catchment Council Inc.

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Funding from the State Government of Western Australia and the Australian Government was provided by the Northern Agriculture Catchment Council for the project.

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PREFACE

Farmers and their communities have been concerned about the effects of rising groundwater and salinity in the Koojan Gillingarra region since the 1970's. With support from Government agencies, surveys were undertaken plans were prepared to tackle problems as they were understood at the time.

Many farmers within the Koojan-Gillingarra region have undertaken significant and innovative groundwater management initiatives over this time. These include:

- Extensive tree-planting to lower groundwater tables,
- Establishing perennial pastures and fodder crops (especially Tagasaste) to reduce groundwater recharge,
- Slotted-pipe drainage to control high water tables on the Moore River floodplain, and
- Earthworks and pumping for surface water control.

In more recent times, the Moore Catchment Council Inc. (MCC) has formed with a key role being to guide integrated natural resource management in the Moore River catchment area – one of four sub-regions of the Northern Agricultural Catchment Council (NACC). These arrangements have enabled to West Koojan-Gillingarra Land Conservation District Committee to raise and address their continuing concerns about rising groundwater and salinity. Local concern has been heightened recently by observations of rapidly rising groundwater occurring, in some areas quite dramatically, at the surface.

The response has been to undertake a project that makes best use of existing information in preparing strategic direction for local action. The Terms of Reference' for the project are:

- *Collate and summarise the relevant information that already exists in relation to the Project Area such as maps, property boundaries etc and prepare the information for overlays on a catchment map.*
- *Develop an outline on the basis of information collated that has gone into the map that identifies areas where groundwater rise will occur or where the major threats are likely to occur.*
- *Develop a catchment plan that strategically identifies areas where future work will need to be carried out and to what scale to minimise the impact of rising groundwater in the region. (Catchment scale hydrological modelling may be required to more accurately estimate the scale of works required and that modelling is beyond the scope of this study)*

- *Develop options for on-ground works and how they will impact on groundwater and salinity control at a broad scale across the catchment, and*

The project is managed by the Project Manager (Bronwyn Williams) and a Steering Committee (John Longman and Bill Lullfitz) on behalf of the landholders within the area. They have engaged a Natural Resource Management Consultant (Viv Read) to guide the planning processes. The key steps of the project were:

- Review of existing information,
- Map information required for planning,
- Undertake a technical workshop in Moora (7th February, 2008),
- Field assessment and discussions with farmers,
- A 'Sundowner' meeting for farmers at Gillingarra (8th February, 2008), and
- Discussion of proposed actions with farmers at Gillingarra (25th July, 2008).

The Local Area Plan is prepared in two parts.

Part A - Understanding the problem

This addresses the main concerns raised by farmers in the area about rising groundwater and salinity. It also provides relevant information for planning.

Part B – Strategies for Local Action

An assessment is made of the options for management. These are then considered in terms of strategies (i.e. integrating different options and identifying where in the landscape these apply). A Triple Bottom Line assessment provides information about the economic, social and environmental costs and benefits for options and strategies.

The Local Area Plan provides direction for management of rising groundwater and salinity within the identified area (the Study Area). It does not prescribe specific actions for individual properties. Decisions about on-farm actions are to be made by those who own the land.

Control of rising water tables and salinity in the Moore River Catchment is a challenge for all involved. There are no simple actions that will solve the problems – if there was a 'sliver bullet', the problems would be solved! This project addresses the challenge based on two main principles; clear understanding of cause of the problem, and planning to adopt the most effective options.

SUMMARY

The Local Area Plan (LAP) for the Koojan Gillingarra area south-west of Moora is to provide a strategic approach for future investment in actions required to manage rising groundwater and salinity. The Study Area is approximately 42,000 Ha with 36 private landholdings and a number of small reserves. The LAP documents natural resources of the area.

The focus of planned activities is on addressing local community concern about rapidly rising groundwater. Four Key Sites have been identified to understand the problems and outline response actions. These and three other selected sites are proposed as demonstrations for similar activities throughout the Study Area. The sites are

Key Site #1	Wandawallah Lake
Key Site #2	Banksia Woodland
Key Site #3	Pine Plantation
Key Site #4	Brewers Lake
Site #5	Airstrip Road
Site #6	Spillway Sand
Site #7	Capitella tributaries

By review of available information and in consultation with local experience, it is concluded that the recently observed groundwater rise is due to changes in the unconfined Poison Hill Greensand and surficial aquifers. These are the shallow groundwater systems that cause seepage in valley floors. The deeper confined Leederville aquifer is rising and may be influencing near-surface groundwater in only a few locations. A preliminary estimate suggests that up to 20% of the area could eventually be affected by high groundwater with associated waterlogging and salinity.

The management response to rising groundwater in the Study Area is based on three key questions:

1. What management options are feasible?
2. Where in the landscape should they be applied?
3. How much of each option is needed to achieve a water balance?

Management action strategies are proposed for options to control rising water tables relevant to the area. The key actions are:

- Integrated surface water drainage,
- Groundwater pumping or siphons,
- Establishing lucerne and other perennial species,
- Commercial farm timber plantations,

- Fodder shrubs (tagasaste, acacias),
- Revegetation of valley floor areas with Brushwood (*Melaleuca uncinata*), and
- Revegetation of granite/bedrock scree, spillway sands and 'Break of slope' plantings.

There is significant interest by landholders within the Koojan Gillingarra Study Area about the potential for commercial use of groundwater based on knowledge about the rate of rise of all groundwater aquifers (including the deeper Leederville aquifer). The 'Capitella/Koojan Pool roads' area is identified where salinity of the Leederville aquifer is least.

The potential for commercial use of groundwater from the Leederville aquifer from this location to reduce the risk of groundwater rise and salinity needs to be recognised. Licensing arrangements for this to occur will require consideration by the Department of Water as it would exceed the current Sub-area water allocation from this aquifer.

ACKNOWLEDGEMENTS

The project has benefited by significant input by Bronwyn Williams, the Moore Catchment Council Coordinator for this area, and the project Steering Committee (John Longman, Bill Lullfitz and Christel Schrank). John Longman, who also represents the West Koojan-Gillingarra Land Conservation District Committee, made further contribution based on his extensive knowledge of the area during field trips and workshop processes.

Information for the project was generously provided by Phillip Commander (Department of Water) through discussions, field site visits and workshop processes. Others who contributed through a workshop were Russell Speed, Paul Findlater and Frank Rickwood (Department of Agriculture and Food, WA), Lana Kelly (MCC East Moore Project), Mark Weston (West Koojan-Gillingarra CDI) and Jill Wilson (Farming Systems Project). Leanne Hartley (Department of Water) provide information about groundwater allocation.

Rob and Judy Barrett provided information about management actions on their property. Peter Isbister provided information about a range of management options based on his experience within the Study Area. Other landholders discussed issues and provided information through meeting processes.

Stacey Rudd prepared the maps and other spatial information management services.

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INTRODUCTION

The purpose of the Local Area Plan (LAP) for the Koojan Gillingarra area is to provide a strategic approach for future investment in actions required to manage rising groundwater and salinity.

The first step is to describe the Study Area.

1 The Study Area

The Study Area is located south-west of Moora. The area is defined as being east of Rowes and Capitella Roads, west of the Moora-Bindoon Road and north of Boxhall Road. Map 1 shows the location of the Study Area.

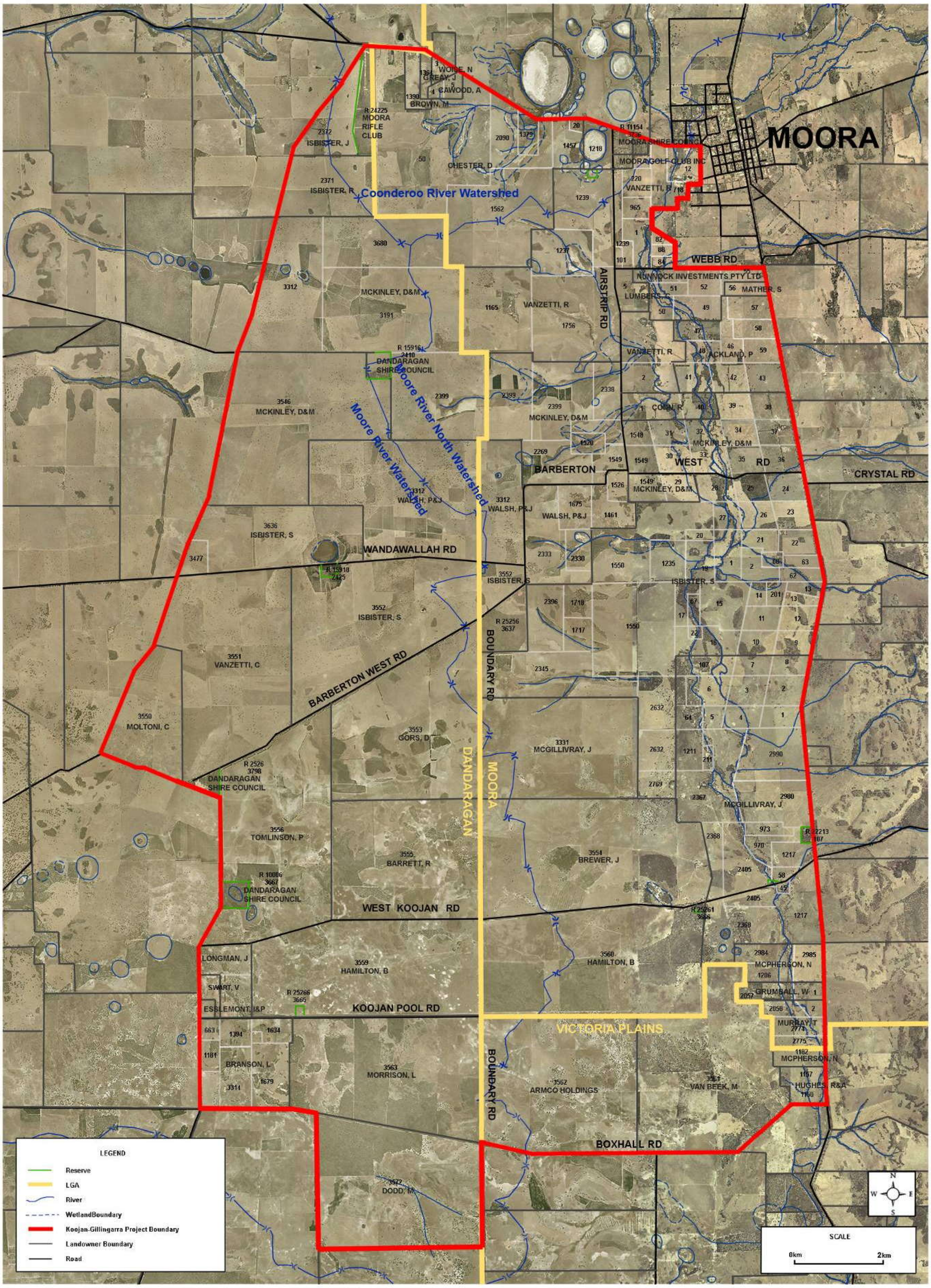
The area is predominantly within the Shires of Dandaragan and Moora. There a small portion within the Shire of Victoria Plains to the south.

The Study Area is approximately 42,000 Ha. There are 36 private landholders within the Study Area. The size of private holding varies considerably within the area. Some properties extend beyond the boundaries. Table 1 lists the landholders within the Study Area.

Table 1 Landholders within the Koojan-Gillingarra Study Area

Ackland, P	Hamilton, B	Nunnock Investments
Armco Holdings	Hughes, R&A	Swart, V
Barrett, R	Isbister, J	Tomlinson, P
Branson, L	Isbister, R	Van Beek, M
Brewer, J	Isbister, S	Vanzetti, C
Brown, M	Longman, J	Vanzetti, R
Cawood, A	Lumbers, C	Walsh, P&J
Chester, D	Mather, S	Woise, N
Conn, R	McKinley, D&M	
Dodd, M	McGillivray, J	
Esselmont, I&P	McPherson, N	
Gors, D	Moltoni, C	
Greay, J	Morrison, L	
Grumball, W	Murray, T	

Map 1 **Location of the Koojan Gillingarra Study Area.**



The area is almost all privately owned and used for agriculture. There are a number of small reserves, as shown in Table 2.

Table 2 Reserves within the Koojan Gillingarra Study Area

Reserve Number	Managing LGA
R6603	Shire of Moora
R11154 (golf club)	Shire of Moora
R34278	Shire of Moora
R25256	Shire of Moora
R22213	Shire of Moora
R25261	Shire of Moora
R15856	Shire of Moora
R15715	Shire of Moora
R24225 (rifle range)	Shire of Dandaragan
R15916	Shire of Dandaragan
R15918	Shire of Dandaragan
R2526	Shire of Dandaragan
R10006	Shire of Dandaragan
R25266	Shire of Dandaragan

South of the Study Area is the *West Koojan-Gillingarra Catchment Demonstration Initiative (CDI)*. This is a project within the West Koojan Gillingarra LCDC that has received significant government funding to address groundwater and salinity issues in very similar landscapes. The actions of the CDI project are based on groundwater modelling and an approved plan. The experience gained from this neighbouring initiative is relevant to this project.

2 Natural Resource Information

Managing water within the Study Area requires knowledge of natural resources.

John Longman, a farmer from within the Study Area and with long-term interest in rising groundwater and salinity, notes that the area was cleared for agriculture 40-50 years ago. There was early realisation that the soils required high application of phosphorus (P) for pasture production. Subsequent use of Blue Lupins to fix nitrogen (N) and stabilise fragile sandy-textured soils was part of the cause of problems with non-wetting soils.

Clearing natural vegetation is well recognised as the major cause of groundwater tables to rise. Re-placement of deep-rooted perennial vegetation with shallow-rooted annual crops and pastures results in a higher percentage of rainfall recharging groundwater aquifers near the surface (unconfined surficial aquifers). John Longman notes that monitoring in some areas over a 25 year period indicated that groundwater tables were rising at the rate of approximately 50 cm/year.

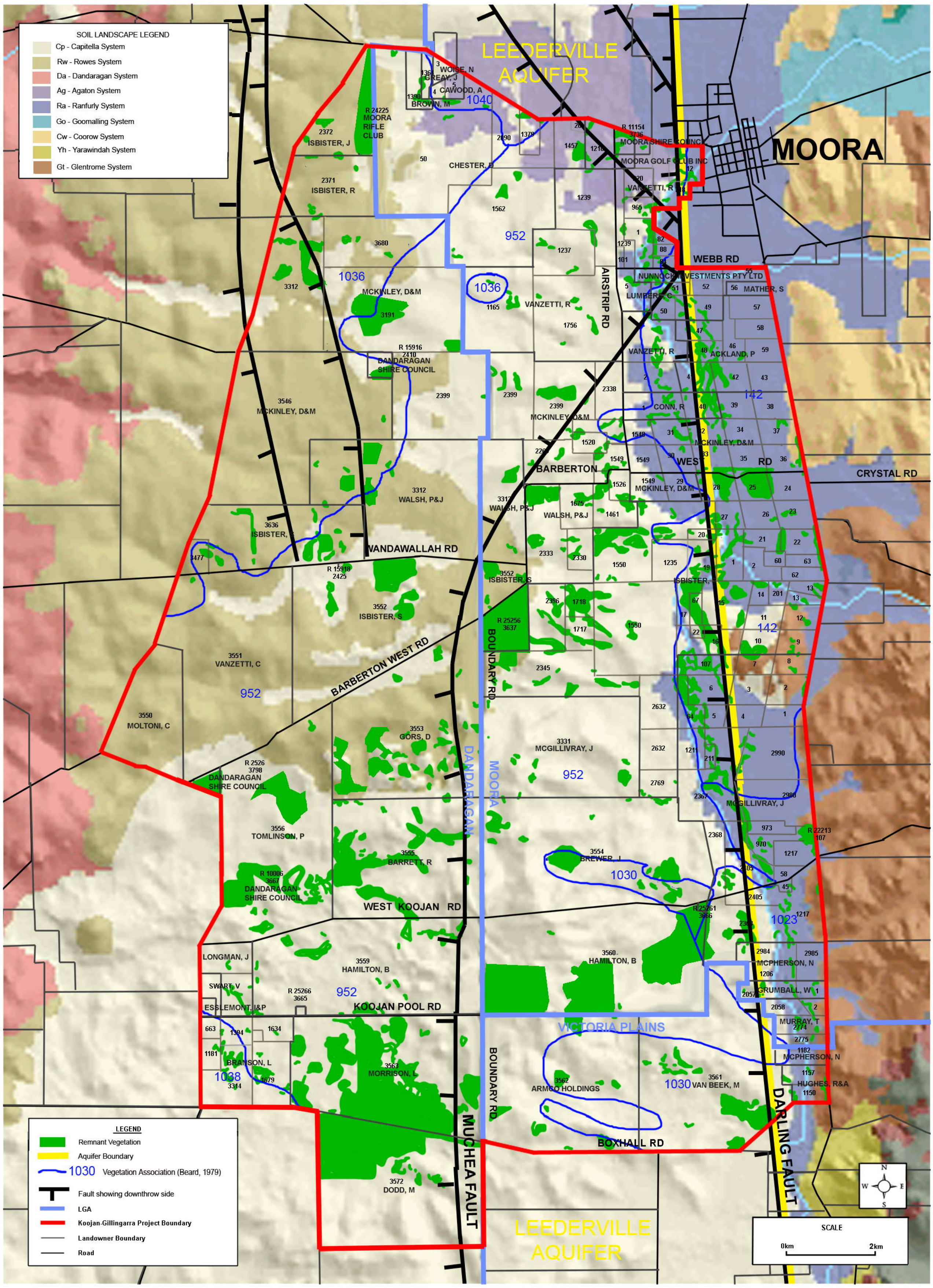
Local observations show how the natural resources are changing with time. The rapid rise of groundwater on Powell's and Isbister's properties in the Minyulo catchment are well known by those in the Study Area. Some estimates indicate that groundwater increased up to 5 meters in 18 months during the early 1990's. The rapid increase in water levels of Wandawallah Lake since 1992 has been obvious to all.

Knowledge of natural resources in the Study Area includes information about changes that continue to occur.

2.1 Soils and landforms

Soils are best considered by the way that they are distributed within the landscape. Map 2 shows the distribution of Soil Landscape units within the Study Area. Soil types may vary considerably within these units, however the unit descriptions are useful as they provide a basis for developing broad directions for management.

Map 2 Soil Landscape units of the Koojan Gillingarra Study Area.



The two dominant Soil Landscape units are the Capitella System (Cp) and the Rowes System (Rw). The Agaton System (Ag) occurs near Moora and the Ranfurly System (Ra) occurs east of the Moore River. A description of these soil landscape units is provided in Table 3.

Table 3 Description of Soil Landscape units within the Koojan Gillingarra Study Area (Source: SLIP, 2005).

Soil Landscape Unit	Description
Capitella	Subdued stripped lateritic plateau, undulating to gently undulating low rises with gently undulating plain including dunes; pale and yellow deep sands, sandy gravels, some duplex; from sandstones plus alluvial and aeolian deposits. Pale and yellow deep sands, sandy gravels and sand over gravel.
Rowes	Subdued partly dissected lateritic plateau, gently undulating plains and gently undulating to undulating rises; yellow and pale sand, sandy earth and sandy gravel; weathered sandstone. Yellow and pale sand, sandy gravels and some gravelly pale deep sand and sandy earths.
Ranfurly	Level to gently undulating plain being a relict flood plain, partially rejuvenated; loamy earths and clay, some duplex; from alluvium. Brown and red loamy earths, loamy and sandy duplexes, saline wet soil and some clay.
Agaton	Gently undulating and level plains, dunefields common; yellow and pale sands, sandy duplexes and shallow sands over clay, iron or carbonate pans, some saline including salt lakes; alluvial and aeolian deposits. Yellow and pale deep sands, minor sandy duplexes and shallow sands over clay, iron or carbonate pans, saline wet soil and salt lake soils.
Glentrome	Stripped, weathered plateau with undulating low hills and rises; loamy earths, loams, loamy gravel and some clay and rock; weathered granite and migmatite. Loamy gravel, red and brown loamy earths and some sandy and loamy duplexes.
Coorow	Undulating to gently undulating rises and intervening level to gently undulating flats. Yellow deep sand, pale deep sand and grey sandy duplexes (some alkaline), some yellow sandy earths, and minor loamy earths and duplexes and rock.

2.2 Natural vegetation

The distribution of remnant natural vegetation is shown in Map 2. The combined area on private and public land (including reserves) is approximately 5,300 ha (12.7% of the Study Area).

The estimated original distribution of the seven different Vegetation Associations is also shown in Map 2. The most commonly occurring association is #952 (dominated by Coastal Blackbutt – *Eucalyptus todtiana*). A description of these is provided in Table 4.

Table 4 Description of Vegetation Associations within the Koojan Gillingarra Study Area (Source: SLIP, 2005).

Vegetation Association	Description	Dominant Species
142	Medium woodland; York gum & salmon gum	*Eucalyptus salmonophloia*
952[1]	Mosaic: Dryandra shrubland; Banksia mixed shrubland	*Dryandra shuttleworthiana; Dryandra carlinoides; Dryandra bipinnatifida* or *Hakea obliqua; Banksia burdettii*
1023	Medium woodland; York gum, wandoo & salmon gum (*Eucalyptus salmonophloia*)	*Eucalyptus loxophleba; Eucalyptus salmonophloia; Eucalyptus capillosa*
1030	Mosaic: Banksia woodland; Banksia mixed shrubland; Melaleuca isolated trees	*Banksia attenuate* or *Melaleuca acerose; Acacia lasiocarpa; Banksia sphaerocarpa* or *Melaleuca rhaphiophylla*
1036	Low woodland; *Banksia prionotes*	*Banksia attenuate; Banksia prionotes*
1038	Medium open woodland; eucalypts, with low woodland; *Banksia attenuata* and *B. menziesii*	*Banksia menziesii; Banksia attenuata*
1040	Medium woodland; York gum & *Casuarina obesa*	*Casuarina obesa; Eucalyptus loxophleba*

Note 1 - Coastal Blackbutt (*Eucalyptus todtiana*) is not mentioned in the description of this Vegetation Association however it is commonly occurring on the mid-slope locations within the Study Area.

2.3 Climatic information

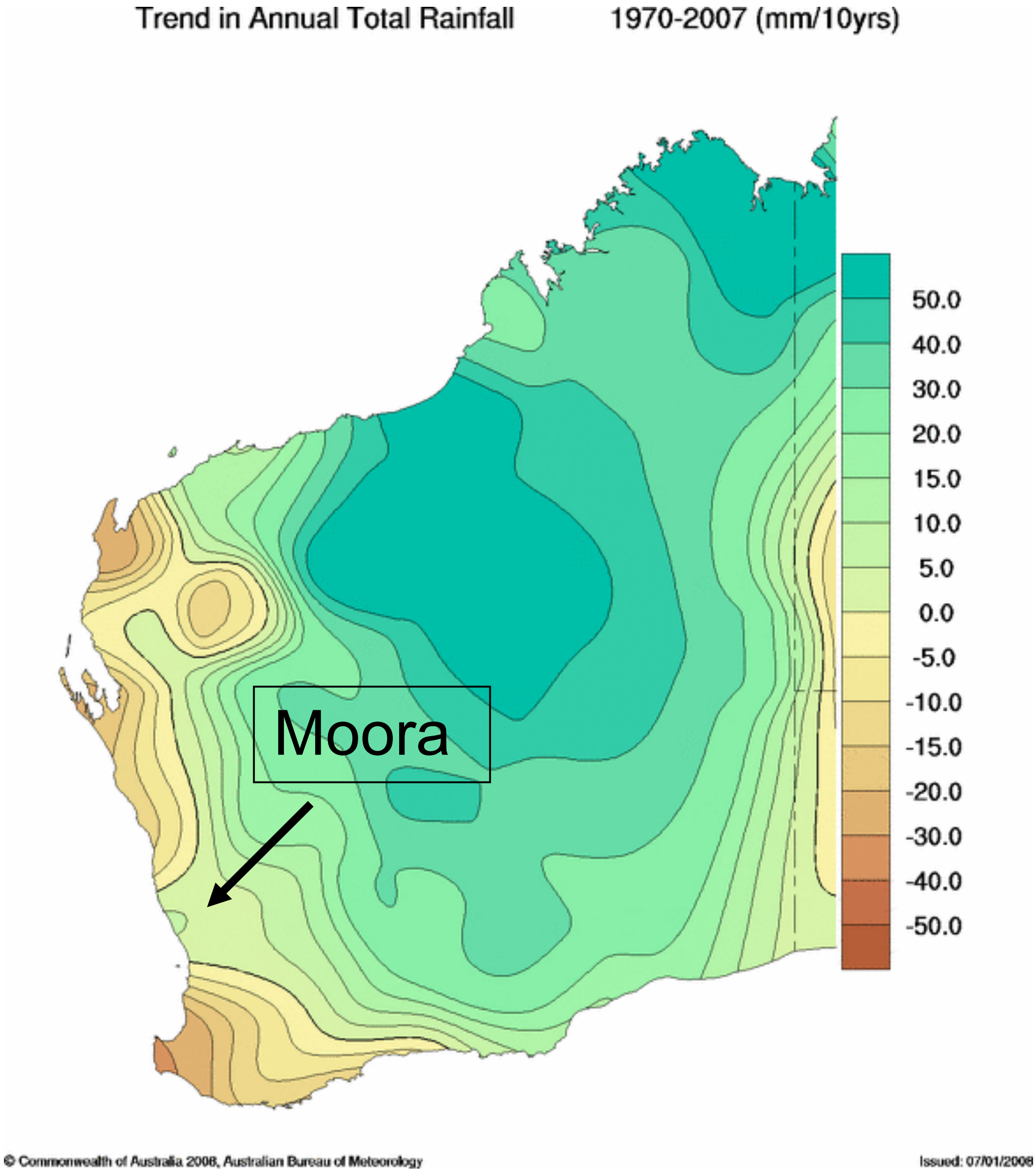
Annual rainfall is as critical to catchment water management as it is to farm production. Table 5 shows monthly and annual climatic information for Moora.

Table 5 Climatic Information relevant to the Koojan Gillingarra Study Area (Source: Bureau of Meteorology).

MOORA	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANN**
Mean Daily Max Temp (°C)	34.4	34.1	31.0	26.4	21.9	18.7	17.3	17.9	20.6	24.5	28.5	32.0	25.6
Mean Daily Min Temp (°C)	17.7	18.1	16.3	13.6	9.9	8.1	6.8	6.7	7.6	9.5	13.0	15.5	11.9
Mean Monthly Rainfall (mm)	11.1	14.3	19.8	25.4	60.9	90.2	88.6	63.8	38.6	24.9	12.8	9.6	459.2
Mean Daily Evaporation (mm)	11.4	10.9	9.2	5.4	3.6	2.1	1.9	2.4	3.7	6.5	8.7	10.4	6.3

Note: temperature information is from a 31 year period (1965-2004) and rainfall information is from a 104 year period (1897-2004).

The recorded annual average rainfall is 459mm for Moora. The average annual rainfall for Dandaragan is 25-30mm higher. Long-term records kept by local farmers (e.g. Rob and Judy Barrett) suggest that the annual rainfall has reduced significantly since the mid-1990's. However, measures of rainfall variability from the Bureau of Meteorology shows there to no discernable long-term trend (i.e. not obviously increasing or decreasing) since the 1970's. The diagram below (as shown by Phillip Commander, Department of Water, at the workshop on 7th February, 2008) shows an analysis of rainfall trends for all of Western Australia. This shows a very slight increasing trend for areas near Moora.



Rainfall records for the last 7 years are less than average. This period is too short to indicate a decreasing trend. It does reflect the very dry period that has been experienced. Moora experienced exceptional flooding just prior to this period.

If it is accepted that there is no long term increase of decrease in annual rainfall, then other causes of groundwater rise need to be considered. These are changes in surface and groundwater processes.

2.4 Surface and groundwater

Surface water

Other than for a small area that drains north to the lakes west of Moora, surface water within the Study Area drains two separate directions to the Moore River. The watershed boundaries for these are shown in Map 1.

Streams draining east to the Moore River are generally short, adequately defined but not always continuous due to ground surface undulation. The volume of water in these streams is relatively small because of their small catchment area. Some streams discharge to the floodplain where they contribute significantly to localised flooding and groundwater rise problems. Those with low gradient (e.g. the stream west of Airstrip Road) are affected by salinity.

Surface drainage west into the Minyulo catchment is poorly defined north of Barberton West Road in the Study Area. This is due to the deeper sandy-textured soils from which there is little run-off. The shallower soils south of this road cause surface water run-off in well-defined streams in the mid-slopes however these streams become poorly defined in lower slope areas and discharge to wetlands (small lakes) or contribute to local discharge areas.

The Moore River channel and associated floodplain is well defined. The 1999 floods occupied the full capacity of the floodplain. The river has an unconsolidated sediment load that can be mobilised by high stream flow. Riparian vegetation is generally limited in extent. Where it occurs, dominant vegetation is sparse. Riparian vegetation is currently not effectively fenced.

Groundwater

Groundwater aquifers and water resources within the Study Area will be described in detail in Part A of this report. It is significant to note that the groundwater and salinity processes within the Study Area are unlike those that occur within the Wheatbelt. This area is a part of the Perth Basin – the dominant geological feature of land west of the Darling Scarp.

Despite concerns about salinity, groundwater in some aquifers of the Study Area are fresh and are allocated for public or private use through licensing arrangements under the *Rights in Water and Irrigation Act,1914 – amended 2001* (administered by the Department of Water). The Study Area occurs within the Victoria Plains Sub Area for the deeper aquifers and Sub-Area 4 for shallow aquifers of the Gingin Groundwater Area (WRC, 2002).

Groundwater in a deeper aquifer (the Leederville aquifer) is fully allocated under allocation licence arrangements and there is no further supply available. Groundwater in the Mirrabooka and Poison Hill aquifers is available for use under licence although is generally not feasible due to limited supply. Groundwater in the surficial aquifers is 50% allocated within Sub-Area 4. There are no licensed allocations for this water within the Study Area due to low water quality and unreliable yield (Leanne Hartley, *pers. comm.*, Department of Water) however licenses are required for all allocations other than for non-artesian stock and domestic use (less than 1,500 kL/year).

Groundwater allocations are managed by the Swan Regional office of the Department of Water.

John Longman – Understanding Water in the Landscape.

John has lived and farmed all of his life in the Koojan-Gillingarra region. He has developed a keen eye for change in the landscape and has a good memory of the way it was. For many years, John has been an activist within his local community through the West Koojan-Gillingarra Land Conservation District Committee to combat rising groundwater and salinity.

Based on his observations, John considers that there is potential for considerable movement of groundwater within the region. According to John, change in catchments adjacent to the Study Area or as far away as the Yarra Yarra catchment upstream of the Moore River catchment can influence local groundwater. This is considered by John to be important because the actions taken by others to management groundwater and salinity could affect the local area.

The recent rapid rise of groundwater within the Study Area is evidence of regional influence according to John. He would like to trace groundwater flow to better understand what is occurring. John considers that the rate at which landscape change is occurring is difficult to explain through local processes.

The potential effect of the Yarra Yarra palaeo-channel on the catchment is of concern to John. He has observed recently formed lakes south of Moora that he attributes to leakage from the channel.

John has developed a good understanding of geological and groundwater processes within the local area. While the Local Area Plan does not assume that there is regional groundwater influence on the local area, the scope for this to occur has been seriously considered.

PART A UNDERSTANDING THE PROBLEM

The purpose of the project is to provide a strategic approach for future investment in actions required to manage rising groundwater and salinity. For this, it is important to clearly understand the problem.

A.1 Issues of concern

A previous assessment of land degradation for land south of Moora (Lenane *et al.,* 1990) shows there to have been 0.5% of the area salt-affected and 5.5% with potential to become salt and waterlogging affected. Moderate changes to farming systems (including adoption of perennial pastures and farm or commercial tree plantations) have been adopted in response to the predicted potential increase in the area of salinity.

However, groundwater has risen significantly in the past few years (estimates of 30-50 cm/year for some sites). This is occurring in a way that is not predictable based on current understanding of catchment hydrology relevant to the area.

Rapid groundwater rise has raised questions within the local community:

- What is the cause of this surprising change in catchment hydrology?
- Why is it occurring adjacent to extensive areas of mature tree plantation, down slope from a vegetated reserve or high in the landscape?
- Why is it occurring during a series of below-average rainfall years and during what seems to be a drying climatic trend?
- What is the extent to which valley floor inundation and salinity will occur?
- What type and level of works are required to control or reverse rapid groundwater rise?
- What is the right balance of revegetation to solve the problems without loss of valuable farm water supplies?

There are 4 sites within the Study Area that demonstrate these concerns:

Key Site #1 Wandawallah Lake

This lake adjacent to Wandawallah Road was a relatively small claypan swamp without permanent water prior to 1992 (J. Longman, *pers comm.*). The water level increased rapidly after 1992, as indicated by the death of pine trees planted during 1995 well above the former high water level (photo 1). While there is only 1 year of groundwater monitoring, the water level is known to fluctuate seasonally. The area of inundation of the lake is now approximately 25 Ha.

This site is located west of the watershed divide (i.e. in the Minyulo Brook catchment area) however it is understood to be a 'terminal catchment' – one that is internally draining (otherwise referred to as a 'sump').

The concern over the recently formed lake extends to the north east where up to 200 ha are considered to be at risk. This area has been recently established with commercial pines. There is additional uncertainty about an area of approximately 400 ha south-west of the lake.

Key Site #2 Banksia Woodland

This site has remnant banksia woodland (*Banksia prionotes*) located within a 260 ha vegetated reserve (ref. R25256) at the intersection of Boundary Road and Barberton West Road. The site is located in the upper slopes of an east-flowing tributary approximately 1500 meters from the watershed boundary on Isbister's property. The tributary has dis-continuous flow to the Moore River floodplain.

Concern about this site is in response to the recent (i.e. since 2004) decline of remnant vegetation being located so high in the catchment and so close to a large area of natural vegetation. (Photos 2 and 3) An estimated 20 ha area of banksia woodlands has been affected so far. The concern extends to other areas of high quality banksia woodland that occur in valley floor situations.

Key Site #3 Pine Plantation

This site is located adjacent to Key Site #2, also on Isbister's property. It is downstream of the above site and occurs within an established pine plantation. The site is also adjacent to the location of a significant pumped farm groundwater supply. The high water table has caused significant tree death.

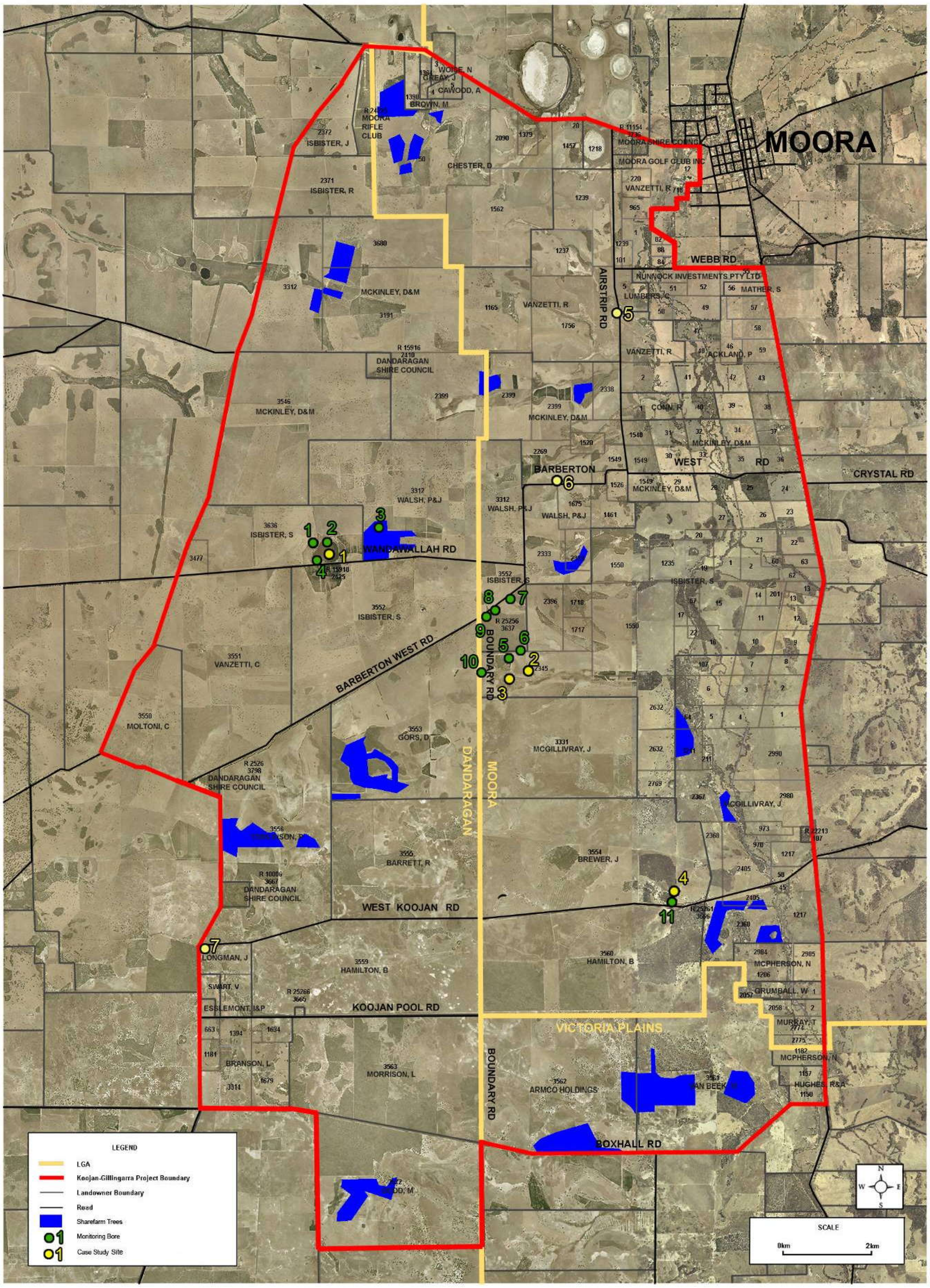
Key Site #4 Brewers Lake

Brewers Lake has formed very recently (i.e. since September, 2004). It is in an area that is internally draining resulting in a wet area of approximately 13 Ha. With adjacent remaining natural vegetation, the site area is 23 Ha. The area of ponded water is 1-2 Ha although this fluctuates seasonally. It is noted as increasing in area each year despite there being below average rainfall (J. Longman, *pers. comm.*). There is a small patch of remnant Wandoo (*Eucalyptus wandoo*) that is normally dry that became inundated during the winter and spring of 2007 (Photos 4 and 5). All vegetation within this remnant area is now dead. This dramatic formation of surface water occurs in an area with poorly defined surface drainage. It appears to be internally draining (i.e. a sump).

The site is located north of Koojan West Road on Brewer's property.

The location of these key sites is shown on Map 3. Monitoring wells constructed to measure groundwater level trends are also shown on this map.

Map 3 Key Sites within the Koojan Gillingarra Study Area.



There are other sites in the Study Area that are representative of concerns about rising groundwater tables and salinity. These are also shown on Map 3 and described below.

Site #5 Airstrip Road

The saline valley floor of a tributary to the Moore River occurs 5 km south on the Airstrip Road. The 150 m wide valley floor has advanced salinity with ungrazed areas colonised by Samphire (Photo 6). The distribution of seepage areas along this tributary and the altering orientation of the stream channel (i.e. it changes to west-flowing just south of the landing ground) suggests that groundwater near the surface is geologically controlled (i.e. there may be influential quartz or dolerite dykes).

Site #6 Spillway Sand

As the landscape has eroded over thousands of years, coarse gravels have remained on the slopes and coarse sands have been deposited in lower slopes and valley floors (Photo 7). These spillway sands are commonly underlain by clay at varying depth and support Banksia woodland vegetation (*B. prionotes* is the dominant species). These features are significant because they are sites of water accumulation in the landscape. If there is adequate slope, they are freely draining (the sandy soils are highly transmissive) however if there is insufficient gradient or if the depth of sand is reducing down-slope, there is high risk of these very shallow groundwater systems to cause waterlogging or seepage.

The typical site for spillway sand is located north of Barberton West Road on Walshes' property. There is concern about the effect of local rise of water tables on healthy Banksia Woodland down stream (Photo 8).

Site #7 Capitella tributaries

The Capitella valley that drains west to the Caren Caren Brook has a series of surface seepage areas located in a broad valley floor west of Capitella Road. The tributaries to the springs are from moderately steep slopes and relatively shallow soils (Photo 9).

The drainage density for the upper slopes is relatively high. There are 9 small tributaries that converge and discharge to the valley floor where the springs occur. John Longman notes that 3 of these now have mid-slope seepage causing stream flow. The broad valley floor has increasing areas of seepage and inundation. Local concern is expressed about the extent to which this extensive groundwater rise might occur. There is an estimated 450 ha of healthy banksia woodland at risk downstream from the Capitella seepage areas.

A significant proportion of the catchment to these tributaries has been recently established with commercial pines (Photo 10). While the immediate concern is about excess seepage in the valley floor, a longer term concern is about losing useful water supplies from the Capitella valley seepage areas if the forested areas intercept too much groundwater. The major issue at this site is about getting the catchment water balance right.

Photo 1: Effect of high water level on pines at Wandawallah Lake.

Photo 2: Banksia death due to high water table

Photo 3: Effect of high water levels on Banksia woodland

Photo 4: Surface water inundation of Wandoo woodland at 'Brewers Lake'

Photo 5: Effect of high water table on Wandoo woodland

Photo 6: Salt-affected valley floor of tributary west of Airstrip Road.

Photo 7: Transmissive 'Spillway sands' in lower slopes

Photo 8: Valley floor Banksia Woodland at risk to high water tables.

Photo 9: Tributaries to the Capitella valley floor

Photo 10: Commercial plantations within the Capitella valley catchment.

A.2 Scenarios for the cause of rising groundwater

Rising groundwater and salinity within the Study Area has been of concern to farmers and the local community for some time. A wide range of ideas have been developed about why these problems are occurring. It is generally recognised that the groundwater processes here are different to those of the Wheatbelt so new understanding of what is going on is sought.

The local ideas about the cause of rising groundwater have been grouped into four 'scenarios'.

Scenario One Leakage from the Palaeochannel aquifer

This scenario considers the potential for the Yarra Yarra Palaeochannel to have altered groundwater characteristics due either to increasing discharge from the Yarra Yarra catchment or due to relatively recent flooding of the Moore River (linked to Scenario Two).

The Yarra Yarra Palaeochannel borders the Darling Fault, beneath the alluvial zone of the southward flowing Coonderoo River system north of Moora (Yesertener *et al*., 2000). It continues south of Moora through the Study Area adjacent to the current channel of the Moore River.

The Yarra Yarra Paleaochannel has been developed by the uplift of the Perth Basin preventing westward drainage across the Dandaragan Plateau, producing a north to south drainage line that has been in-filled with sediments between 23.5 and 37 m thick, consisting of sand, gravel and clay (Yesertener *et al.*, 2000).

Scenario Two Delayed effect of Moore River flooding

The Moore River flows from north to south through the eastern portion of the area, and is prone to heavy flooding in winter. On the 19th to the 21st of March 1999, intense rainfall within the Moore River Catchment resulted in extensive flooding within the town of Moora, with 166mm of rainfall falling near Moora. This was estimated as a 1 in 100 year flood. During the period 26th to 28th of May 1999, 109mm of rain fell near Moora causing the town to flood for a second time. The Moore River floodplain was flooded for the third time after heavy rains during 17th and 18th of August in 1999.

This scenario suggests the effect of extensive flooding of the Moore River floodplain within the Study Area as a cause of groundwater rise.

Scenario Three Leederville aquifer discharge

There are two main groundwater flow systems within the Study Area. These are clearly described in Section A.3. This scenario suggests that the deeper Leederville aquifer is influencing groundwater flow systems near the surface within the Study Area.

Scenario Four Surficial aquifer rise

This scenario suggests that the recently observed groundwater rise is due to changes in the unconfined surficial aquifers. These are the shallow groundwater systems that cause seepage in valley floors.

These aquifers are also described in Section A.3.

The management response to each of these scenarios is radically different. It is important to establish the cause of groundwater rise in the Study Area. This requires knowledge and an understanding of groundwater systems.

A.3 Understanding Groundwater Systems

There are several relevant studies that help in our understanding of groundwater systems in the Study Area. These are briefly reviewed before providing a description of groundwater systems. A more detailed review of all relevant research documents is provided separately.

A.3.1 Review of relevant research

Kay, T. (1999) A Hydrological Assessment of the West Koojan – Gillingarra Land Conservation District MSc Env. Geol. thesis, University of Wales, Cardiff UK.

This is the most important study relevant to the area. It aimed to map groundwater aquifers. It provides a detailed description of deep and shallow groundwater systems. This document contains relevant descriptions of the groundwater processes and an assessment of the potential for future groundwater rise. An analysis is provided of groundwater trends and a set of 'conceptual models' about how groundwater moves through near surface aquifers is provided.

Yesertener C., Commander, D.P, and Muirden P.D. (1999) *Groundwater and surface water outflow from the Yarra Yarra Lakes, Western Australia*

This reports on a range of significant research projects to assess the hydrological connection between the Yarra Yarra Catchment and the Moore River catchment focused on the Yarra Yarra Lakes. This lake system is described as 'terminal lakes' as they have not over-flowed in 'living memory', but may have over-flowed in 1917 and 1918. The lakes estimated to overflow one-in-50 years. The volume of lakes estimated to be 200M m^3. Groundwater discharge from all systems to the Moore River catchment is relatively small (estimated to be 6.6 M m^3/year).

The Yarra Yarra and Moore catchments are hydro-geologically linked although surface and groundwater flow between the systems are small.

The palaeochannel beneath the lakes has low hydraulic gradient so additional flow into the lakes is unlikely to increase groundwater flow through the palaeochannel sediments.

Earth Tech Engineering (2004) *West Midlands Hydrology Project- the Impacts of Hydrological Issues on Biodiversity and Agriculture in the West Midlands Region* Stage One Report Prepared for the Northern Agricultural Catchment Council

This study provides a good description of the geology, including major faults, of the Perth Basin. It also provides a useful description on the Yarra Yarra palaeo-drainage system. Analysis of groundwater trends is not directly relevant to the Study Area.

Global Groundwater (2005) *West Koojan-Gillingarra Catchment Demonstration Initiative(CDI) – Research and Analysis Report*

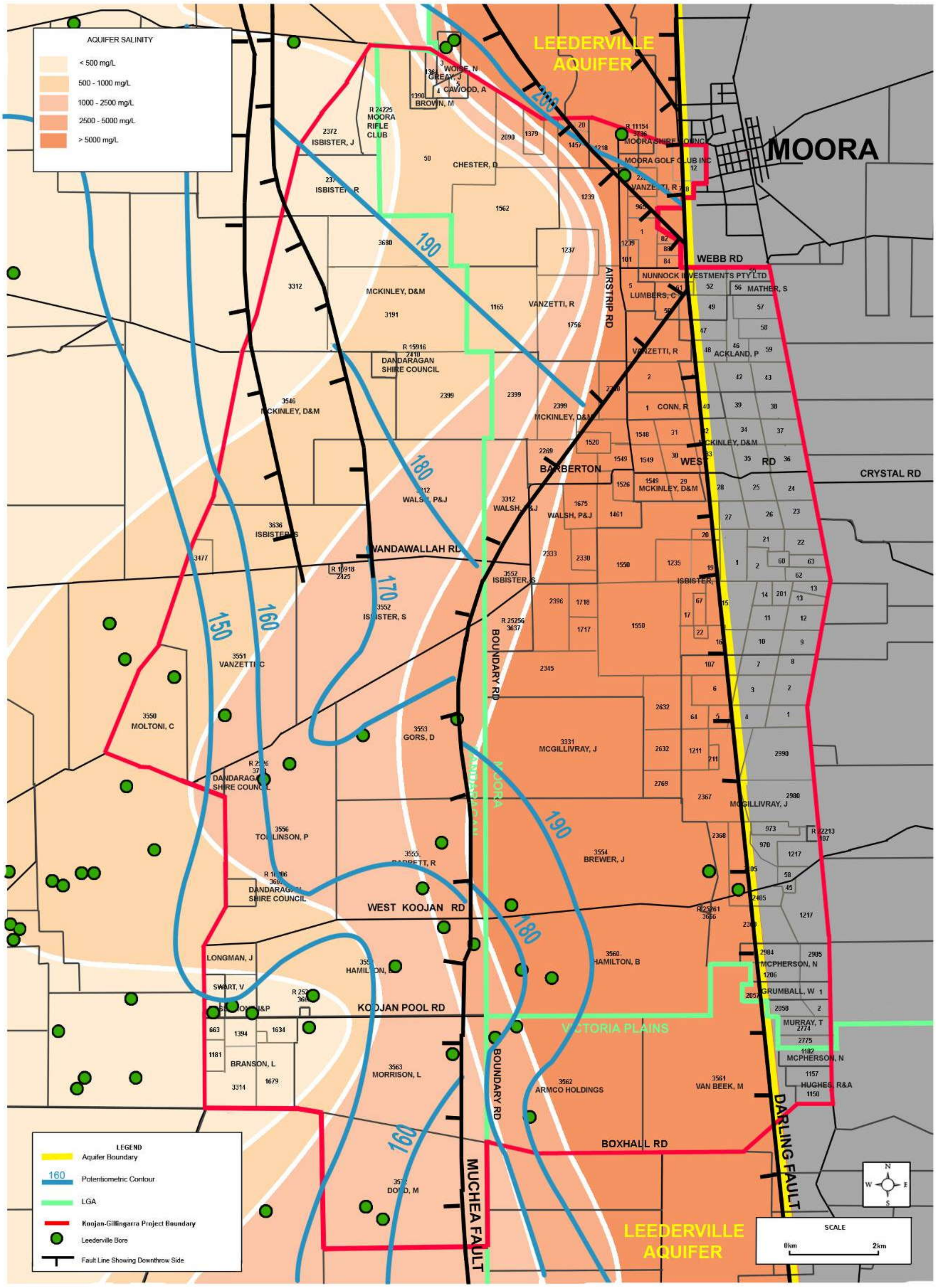
The study was undertaken for the *Catchment Demonstration Initiative* (CDI) project of the West Koojan - Gillingarra LCD, located immediately south of the Study Area. It provides a relevant description of groundwater aquifers and flow processes.

A.3.2 Description of groundwater systems

The Study Area is located within the Perth Basin. This is a geological description of landscapes west of the Darling fault line extending north towards Geraldton and south to Augusta. This is significant because there is a series of groundwater aquifers at differing depths and they are generally fresh. The deeper aquifers are significant for public and commercial water use allocated under regulated licensing arrangements.

The location of the different aquifers is determined substantially by geology and landforms. Within the Study Area, there are a series of geological Fault Lines, as shown on Map 4.

Map 4 Groundwater rise potential and aquifer salinity in the Koojan Gillingarra Study Area (Source: Kay, 1999).



The *Darling Fault* occurs west of Moora and aligns with the Moore River channel within the Study Area. The *Muchea Fault* is also generally orientated north-south although deflects to the north-east and intersects with the Darling fault within the area. The *Barberton Terrace* is the area between these two faults.

West of the Study Area is a significant landform feature – the *Dandaragan Scarp*. This can be clearly observed in places as a steep scarp-face. The area between this scarp and the Darling Fault is known as the *Dandaragan Plateau*. This has relatively similar soil and landform patterns extending north to about Mingenew however groundwater characteristics north of Moora differ to those of the Study Area so caution is required in extrapolating information from the entire landform unit.

Figure A1 provides a cross-sectional representation of the groundwater aquifers that occur. The diagram is based on information obtained from drilling an east-west transect of deep monitoring wells central to the Study Area (the Barberton Section). There is also a transect of monitoring wells just north of the area (the Moora Section) and one just to the south (the Gillingarra Section).

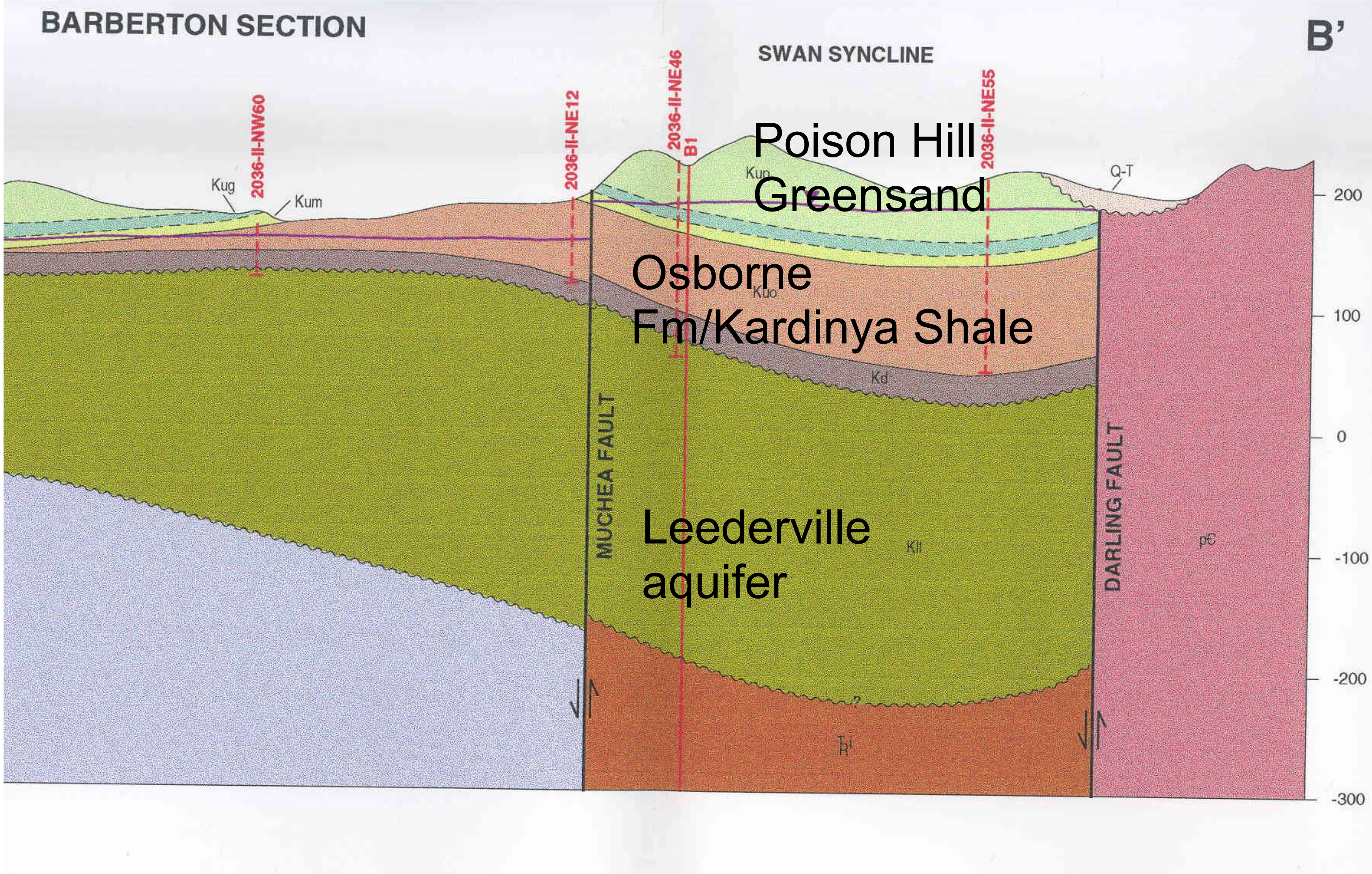
The cross-sectional diagram shows two major groundwater aquifers:

Poison Hill Greensand aquifer – associated with the similar Mirrabooka aquifer which occurs further north in the Study Area, and

Leederville aquifer – sometimes described with the Parmelia aquifer can occur just beneath the Leederville.

These two aquifers are separated by the *Osborne/Kardinya shales*. These form an impermeable layer of marine deposits which confined the Leederville aquifer. There is effectively no transmission of groundwater upwards or down through the shales.

Figure A1 Cross-sectional representation of groundwater systems in the Study Area (Source: T. Kay, 1999, modified by P. Commander, Department of Water).



Over-lying the major aquifers shown in Figure A1 are surface soils, including areas of deep sands. Groundwater in these are described as *Surficial aquifers*. They are generally less than 10 meters in depth, of limited yield and with variable water quality.

The deeper *Yarragadee aquifer* is confined by the Otorowiri Silts. This aquifer occurs west of the Muchea Fault in the Study Area at considerable depth. Discharge from this aquifer is considered to be off-shore. The age of the water in this aquifer is 30,000 - 35,000 years.

A brief description of the major groundwater systems is provided from information contained within Tanya Kays' research thesis (Kay, T. 1999).

Characteristics of the Leederville aquifer:

The Leederville aquifer is the major source of water public and commercial supply.

- Confined, multi-layered flow system, underlain by impermeable Otorowiri silts,
- Groundwater is 4,000 – 30,000 years old,
- Moora draws 2,500 m^3/day for water supply,
- General flow is north to south, with some higher potentiometric head east of the Muchea Fault, (see Map 4),
- Groundwater in the Leederville aquifer is rising 10-50 cm/year in the Study Area.
- Substantial rise in levels of the aquifer over the last 30 years,
- Recharge occurs west of the Study Area and is associated with drainage lines, and
- Discharge is known to occur south of the Study Area. It is by leakage to the Yarragadee, and to the Moore River (base flow), (and possibly to salt lakes west of Moora where Osborne may be thin).

Characteristics of the Poison Hill Aquifer:

The Poison Hill aquifer (and Mirrabooka aquifer) has only recently been recognised in the area (Kay and Diamond, 2001). There is currently insufficient data to determine the full extent of these aquifers and further information is required to improve the estimates of their volume and sustainable yield (WRC, 2002).

- Numerous perched aquifers within the area, with groundwater 30-40 m deep increasing in occurrence towards the Darling Fault,
- Flow is probably related to topography and distribution of sandstone and shale inter-beds,
- Outcrops in the Study Area including lateritic deposits,

- Recharge is generally directly from rainfall although there are some permeable confining layers,
- Discharge generally occurs as springs (causing waterlogging problems where drainage is poor),
- Estimate recharge is 4% of rainfall (32 Mm^3/year), and
- Salinity of discharge is higher towards the Darling Fault.

Characteristics of the surficial aquifers:

The substrate (underlying material) of these aquifers are relatively young in geological time (less than 2 million years). The surface soils are much younger, measured in thousands of years.

- Formed by aeolian (wind blown), fluvial (down slope), alluvial (river deposition) and lacustrine (lake deposition) sediments overlying impermeable sediments
- Sands of 40m depth, with fresh groundwater (yield of ~15m^3/day) within a few meters of the surface.
- Rainfall and run-off recharge and discharge is to local creeks,
- Difficult to separate perched surficial aquifers from Poison Hill aquifer,
- 25% of Kay's study area (similar to this Study Area but extends south to Mogumber Road West) has water depth that is <2 meters and conservatively 20% is 2-5 meters,
- Salt lakes are an unusual occurrence in this area. Moderately saline lakes west of Moora could be the result of discharge from the Leederville aquifer (P. Commander, *pers. comm.)*.

A.4 Monitoring and groundwater trends

A.4.1 Trends in the Leederville and Yarragadee aquifers

Groundwater table levels are measured in monitoring wells. East-west transects of deep wells (described in Section A.3.2) show that water tables are rising at 10-50 cm/year in Leederville aquifer and 10cm/year in the Yarragadee aquifer

The location of monitoring wells for the Leederville aquifer is shown in Map 4.

The Leederville aquifer is 'confined' (by the Osborne/Kardinya shales) so that the potentiometric head (potential water level if not confined) is higher than the actual water level. Map 4 shows potentiometric iso-lines (lines of equal value) for the Leederville aquifer derived from Kay, 1999. These show the potentiometric level near Moora to be close to the ground surface. This may be the cause of the seepage lakes west of Moora where the Osborne/Kardinya shale layer is thought to be thin or fragmented. Elsewhere, the potentiometric level is lower than the land surface and is confined by the shale layer so is unlikely to be expressed at the ground surface. It is of interest to note that the Muchea fault affects the potentiometric level in this aquifer (as shown in Map 4).

The salinity of the Leederville aquifer is also shown in Map 4. This shows an increasing west to east trend from under 500 mg/Lt to over 5000 mg/Lt. The source of salinity is considered to be from land east of the Darling Fault (WRC, 2002).

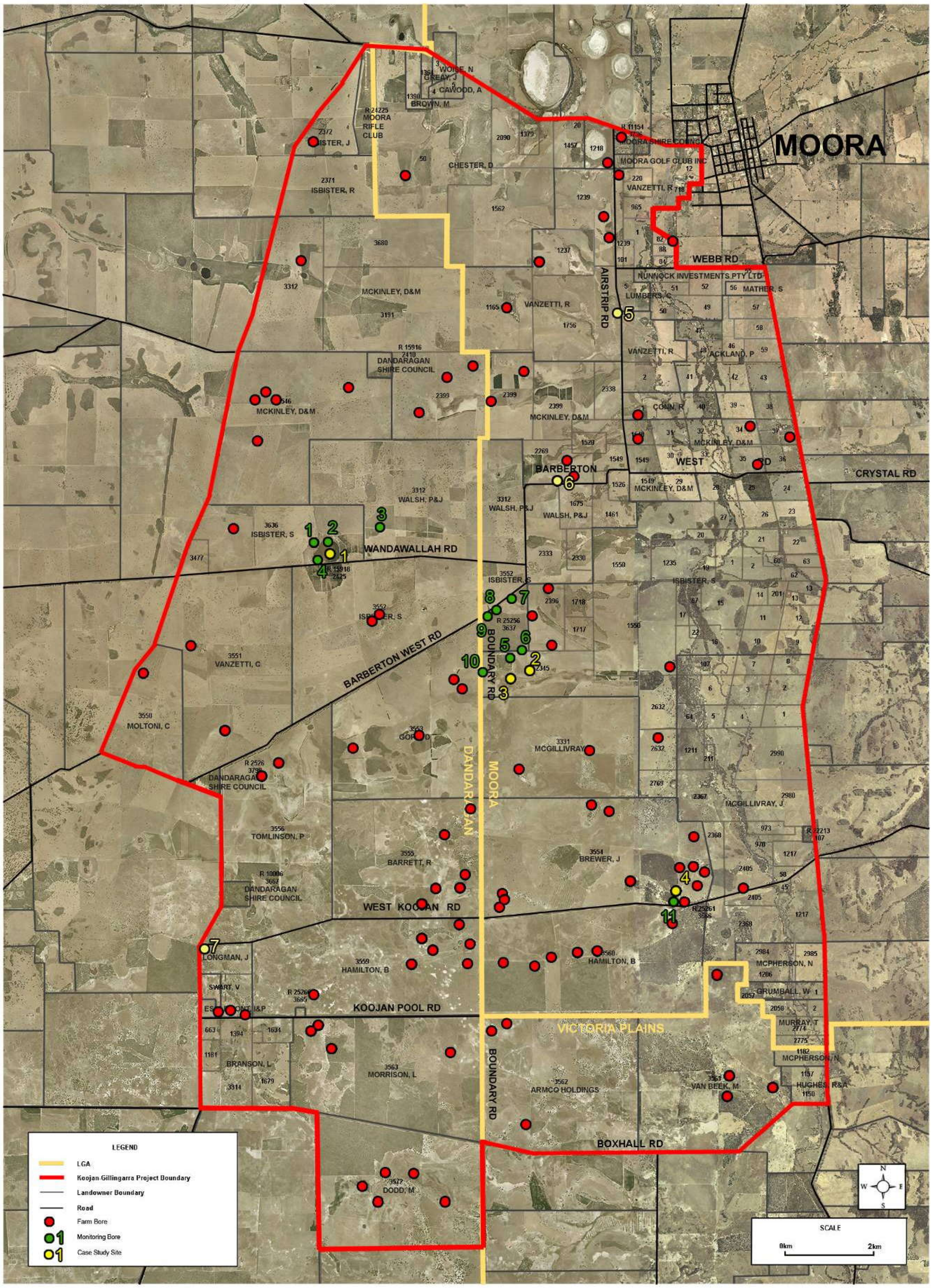
A.4.2 Trends in the Surficial and Poison Hill aquifers

The study undertaken by Tanya Kay identified more than 1000 farm bores, wells, soaks and dams. Approximately 10% of the bores are drilled into the Leederville aquifer. The remaining bores access shallow perched groundwater in the surficial and Poison Hill aquifers.

Wells generally consist of shallow abstraction points between 2 and 10m deep, often lined with concrete. Soaks are shallow excavations, dissecting shallow water tables 1-2m below the ground surface. Dams are generally located in the natural drainage flow of surface water run-off.

Map 5 shows the location of all bores within the Study Area.

Map 5 Location of bores in the Surficial and Poison Hill aquifers within the Koojan Gillingarra Study Area (Source: Kay, 1999).



As a part of research undertaken by Tanya Kay, many farm bores were located and revisited to obtain water levels in 1999. The results of this survey are shown in Table A.1, which shows the rate of increase in water levels. The bores identified as 'Kup' are in the Poison Hill aquifer. Some show a rapid rate of rise (over 50 cm/year for a period of over 30 years).

It is difficult to differentiate between the Surficial and Poison Hill aquifers in the monitoring information that is available.

There are further shallow monitoring wells recently installed at the key Sites. The location of these wells is shown in Map 3. There is insufficient information to identify trends at this stage. Other monitoring of unconfined groundwater at Koodgee Swamp (immediately south on the Study Area on Boxhall Road) shows very high seasonal fluctuation (Speed and Lefroy, 1998).

Table A.1 Farm bore survey information (from Table 8.2, Kay, 1999).

Table 8.2 Water level rise in farm bores

Location number	Property owner	Date visited	Date Drilled	Bore ID	Easting	Northing	Original SWL m BGS	New SWL mBGS	Increase cm/yr	Lithology
2	F Rogers	27/05/99	1960	2036-2-SE-0018	403075	6576390	36.60	27*	24.60	Kll
		27/05/99	1960	2036-2-SE-0022	401960	6571780	18.29	0*	50.80	Kup
		27/05/99	1964	2136-3-SW-0027	406690	6575320	18.29	1.5*	48.00	Kup
4	J Longman	28/05/99	1972	2036-2-NW-0060	391744	6586800	24.08	11.00	48.40	Kll
8	P & J Thomlinson	31/05/99	1960	2036-2-NE-0048	392660	6593340	36.57	10.40	67.10	Kll
10	M & K Van Beek	3/06/99	1982	2036-2-NW-0050	403989	6587889	30.50	24.00*	35.80	Kup?
11	B Morrison	3/06/99	1973?	2036-2-NE-0041	393580	6586500	27.40	11.90	60.70	Kll
12	J Brown	22/06/99	1967	2036-2-NW-0040	385399	6589133	21.34	11.50	30.80	Kll
13	R Smith	23/06/99	1990	2036-2-NE-0046	398436	6589537	33.00	24.10	65.60	Kll
14	M Campbell	25/06/99	1964	2036-2-SE-0032	393811	6577197	6.10	0.00	17.40	Kup
16	I Griffiths	7/07/99	1965	2036-2-SW-0005	392454	6581714	48.55	26.20	66.40	Kup?
17	P Fleay	7/07/99	1963	2036-2-SE-0009	395184	6581309	53.43	28.70	68.70	Kll
		7/07/99	1969	2036-2-NE-0036	398685	6586668	46.30	34.07	40.80	Kll?
19	C Moltoni	8/07/99	1965	2036-2-NW-0068	387281	6590810	21.34	13.95	21.70	Kll
23	D McKinley	11/08/99	1979	2036-1-SE-0051	393030	6606290	7.60	0*	38.00	Kup
		11/08/99	?	2036-1-SE-0031	401786	6601527	0.00	0*	0.00	Kup
24	B Branson	12/08/99	1964	2036-2-NE-0022	397563	6588672	30.48	16.10	41.00	Kll?
27	J Kelly	13/08/99	?	2136-3-SW-0021	408447	6577480	5.00	5*	0.00	Kup
34	B Cahill	17/08/99	1963	2036-2-NE-0017	396518	6594066	42.67	31.00	32.40	Kll
		17/08/99	1988	2036-2-NE-0034	394636	6593661	36.00	31.08	44.70	Kll
35	C Woods	17/08/99	1969	2036-2-SW-0016	388909	6583046	71.32	46.15	83.90	Kll

SWL = Static water level
mBGS = Metres below ground surface
* = Information obtained from farmer
[shaded] = Field measurement 1999

A.5 Implications for the Koojan Gillingarra Study Area

A.5.1 Salinity and waterlogging risk areas

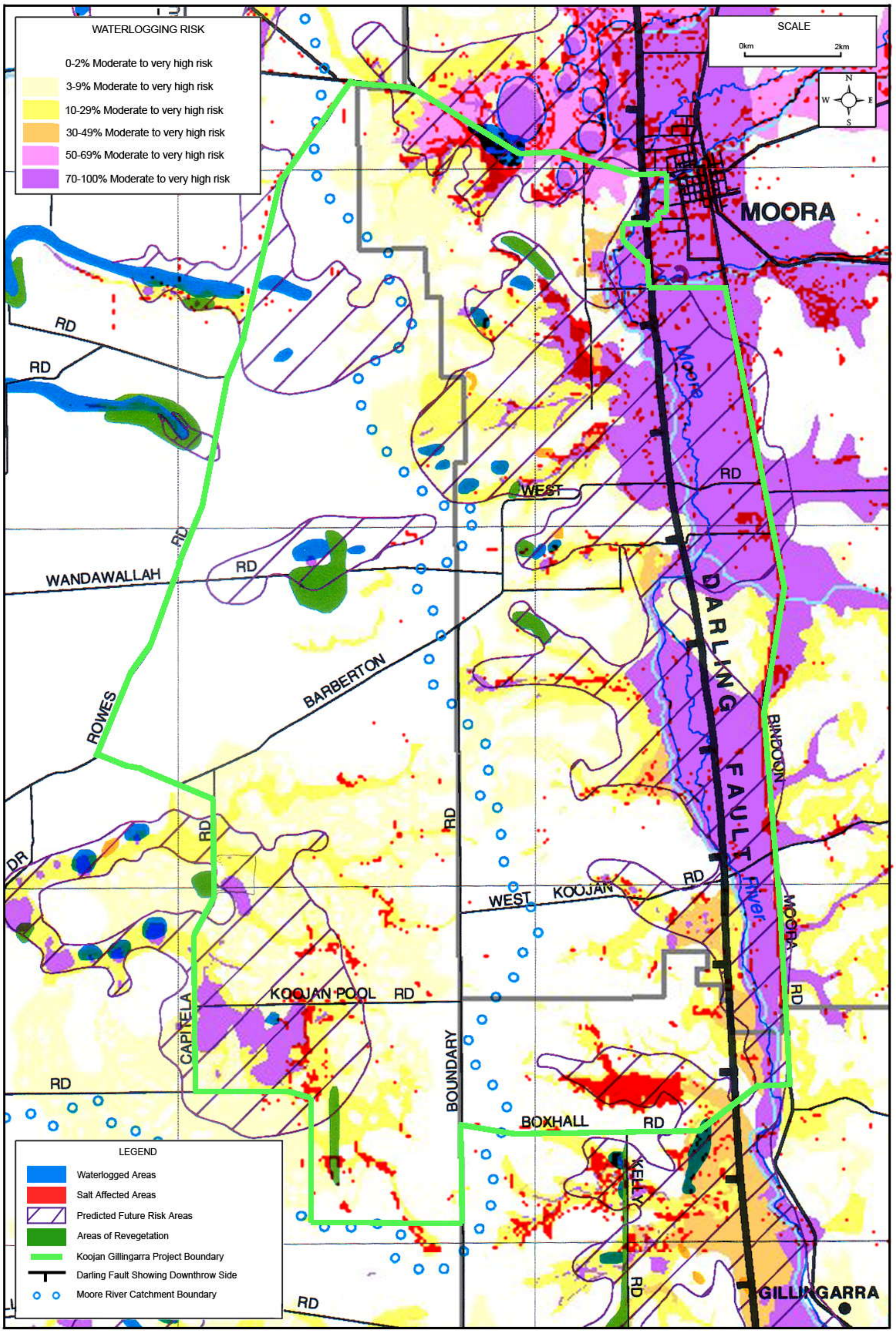
The potential for groundwater rise and salinity risk in with Study Area has been assessed in three ways. The first is by review of available information, including Tanya Kay's research.

Map 6 shows areas identified as being affected by salinity and prone to waterlogging. It shows the higher risk of waterlogging in the Moore River floodplain, especially for land south of Moora. Areas prone to waterlogging are at higher risk to salinity. This risk is well known to those that live and farm in these areas.

Kay (1999) has combined information about waterlogging, current high water tables, areas with high water level risk in the Surficial and Poison Hill aquifers topographic contours and soils risk analysis to provide a risk assessment for the area of her research. Based on the rising groundwater trend for the Surficial and Poison Hill aquifers (of 40cm/year), Kay estimated that 20% of the area will be at risk within 10-15 years. This estimate was made 9 years ago so it is expected that the effect of this groundwater rise may be experienced over the coming years. The area at risk occurs primarily within the Capitella and Ranfurly soil/landscape units (shown on Map 2).

It should be noted that the distribution of the Poison Hill aquifer (and the associated Mirrabooka aquifer) is not well known within the Study Area so the accuracy of the boundaries of the areas identified to be at risk is not high. It can be assumed that within the areas identified, the risk will be greatest in valley floor situations. There may well be additional valley floors at risk that are not identified in Map 6.

Map 6 Salinity, waterlogging and potential Leederville Aquifer groundwater rise within the Koojan Gillingarra Study Area (Source: Kay, 1999).



Map 6 shows one area of risk around the intersection of Capitella Road and Koojan Pool Road. Kay (1999) observes that the potentiometric head of the Leederville aquifer is 10 meters below the ground surface and rising at the rate of 40-50 cm/year and estimates the additional risk due to this aquifer that could occur in 20-25 years. This estimate was made 9 years ago. The potential for groundwater from the Leederville aquifer to access the surface in this area is considered possible as the Osborne/Kardinya shales are understood to be thinner or fragmented in this location.

There is currently no effective monitoring of the Leederville or the unconfined aquifers in the Capitella/Koojan Pool roads location.

A.5.2 Assessment of salinity and waterlogging risk for Key Sites.

The second assessment of the potential for groundwater rise and salinity risk in with Study Area is from technical assessment of the Key Sites (described in Section A.1) at a workshop held in Moora on 7th February, 2008 where the assessment was led by Phillip Commander (DoW) and Russell Speed (DAFWA).

Key Site #1 Wandawallah Lake

The Leederville aquifer was shown to be 50 meters beneath the land surface and confined by a significant depth of the Osborne/Kardinya shales. It is very unlikely that this aquifer has any influence over the groundwater rise that has occurred.

Map 2 shows the distribution of soil/landscape units within the Study Area. This identifies and area of the Capitella unit locked within the elevated areas of the Rowes unit. This suggests there to be no external drainage from this area so Wandawallah Lakes is performing as a sump.

The distribution of the Capitella unit shown in Map 2 indicates that drainage may have previously occurred to the west. Assessment of topographic contour lines indicates that groundwater flow is currently towards the south west from the lake. It is likely that groundwater is moving from north east to south west with only temporary expression in the lake. This would account for water in the lake being fresh while there is salinity on the south west side of the lake. Salinity would be caused by continuous evaporation of mildly saline water.

With this information, it is concluded that the groundwater rise is due to Surficial aquifer processes. There could be additional influence from the Poison Hill aquifer, if it occurs in the area, but this is not known.

Key Site #2 Banksia Woodland

The Leederville aquifer is more than 25 meters below the ground surface at this site and the Poison Hill aquifer is considered to be too low to be influential. While there is an area of natural vegetation adjacent north of the site, there is a larger area cleared for agriculture west of this site. It is considered that shallow drainage of groundwater from this area would account for the seepage that is now occurring.

Banksia woodland occurs commonly on 'spillway sands' where water from the landscape accumulates. It is suggested that this is the process at this site and that seepage is occurring due either to a change in gradient or decreasing depth of spillway sand.

Key Site #3 Pine Plantation

This site is located adjacent to Key Site #2. It is suggested that the same surficial aquifer processes are occurring at this site.

It is understood that a substantial farm water supply is pumped down slope from this site. The depth from which this supply is pumped is unknown at this stage, but is likely to be from a deeper aquifer, possibly confined and independent of the surface water accumulation processes.

Key Site #4 Brewers Lake

The way that surface water has ponded at this site clearly indicates there to be inadequate external drainage even though this site is located near to the Moore River floodplain.

The cause of water accumulation at this site occurring recently and rapidly remains uncertain. The occurrence of Wandoo trees at this location suggests that the clays are a former lake bed (P. Commander, *pers. comm.*). This would indicate the potential for deeper groundwater access to the surface in previous times. The Leederville aquifer has potential to discharge at the surface due to the sometimes fractured substrate associated with the Darling fault.

While there is some potential for deeper groundwater access at this site, there would be little doubt that surficial aquifer processes would be contributing significantly, especially as external drainage appears to be truncated.

The potential for the Poison Hill aquifer to also discharge at this site is unknown.

It is interesting to note that Map 6 shows this area to be hazardous based the assessment by Kay (1999).

A.5.3 Assessment of the Scenarios of the cause of groundwater rise and salinity risk.

The third assessment of the potential for groundwater rise and salinity risk in the Study area is of the four scenarios developed to explain the processes (as described in Section A.2).

Scenario One Leakage from the Palaeochannel aquifer

The Yarra Yarra palaeochannel occurs within the Study Area. It is quite deep and is filled with transmissive alluvium. Saline groundwater flow is in a southerly direction. While the palaeochannel may be influencing the risk of salinity within the Moore River floodplain (where it occurs), it is unlikely to be the cause of groundwater rise or salinity in any other areas. The palaeochannel is saturated and has always been saturated so can not have an additional influence on the area. The direction of groundwater flow is to the south so would not influence areas to the west of the floodplain. The Leederville aquifer has rising potentiometric levels near the location of the palaeodrainage channel so is unlikely to be contaminated by it.

Scenario Two Delayed effect of Moore River flooding

The Moore River flood flows in 1999 did occupy the floodplain. Detained water in this area would have added to groundwater rise and the risk of salinity in this locality. There would be no influence on areas with higher elevation to the west of the floodplain.

Scenario Three Leederville aquifer discharge

Information provided in Sections A.5.1 and A.5.2 indicates that there is potential for the Leederville Aquifer to access the ground surface within the Study Area. This could occur in the Capitella/Koojan Pool roads area and near Moora. It is also identified as a possibility for Key Site #3 (Brewers Lake). It is unlikely that it is commonly occurring in other parts of the Study Area due to its depth beneath the ground surface.

Scenario Four Surficial aquifer rise

Considering the time since clearing the land of natural vegetation for agriculture (30-50 years), it is quite likely that most observed groundwater rise is caused by unconfined Surficial aquifers. The extent to which the deeper Poison Hill and associated Mirrabooka aquifers contribute to the rise is not known. However, processes of recharge to these deeper aquifers are in common with those for Surficial aquifers so management strategies would be similar.

From the analysis of groundwater rise and salinity risk in the Koojan-Gillingarra Study Area, it can be concluded that the primary cause is by local groundwater flow systems with the occasional exceptions for where the Leederville aquifer may be discharging towards the surface.

Pre-clearing recharge has been estimated at 2-4% or 10-20mm of annual rainfall. An analysis of available data suggests that recharge may now be as high as 30% of annual rainfall (Kay, 1999). This substantial increase in groundwater recharge directly affects the unconfined Surficial aquifers. It only indirectly affects the deeper confined aquifers.

Previous research (Yesertener *et al*., 2000) concludes that there is hydrological connectivity between the Yarra Yarra lakes and the Moore River catchment but that the probability of surface flow is small and the amount of groundwater contribution is small. Land management in the Yarra Yarra catchment will have no effect on rising groundwater in the Study Area.

Similarly, there is no information to suggest that there are other inter-regional or cross-catchment groundwater flow systems that influence the Study Area.

The focus of management to control groundwater rise and salinity within the Koojan Gillingarra Study Area should remain within the boundaries of the Study Area. Strategies to manage Surficial aquifer systems and to evaluate potential discharge from deeper systems (i.e. the Leederville and Poison Hill aquifers) are required.

PART B STRATEGIES FOR LOCAL ACTION

The management response to rising groundwater and salinity in the Koojan-Gillingarra Study Area is based on current understanding of groundwater flow systems. This requires the major focus to be on managing the unconfined Surficial aquifers.

There are three questions that need to be addressed for local action:

4. ***What management options are feasible?***
5. ***Where in the landscape should they be applied?***
6. ***How much of each option is needed to achieve a water balance?***

These three questions are considered separately. Section B.1 assesses suitable options. Section B.2 identified positions in the landscape to which the options are most effectively applied, and Section B.3 provides direction for estimating the extent of options needed for achieving the water balance.

B.1 Assessing the Options

Options to control rising water tables and salinity that are relevant to the Koojan Gilligarra Study Area are assessed in Table B1. These are listed as four management action strategies:

STRATEGY 1 – INTEGRATED WATER MANAGEMENT

STRATEGY 2 – PLANT BASED MANAGEMENT

STRATEGY 3 – SOIL MANAGEMENT

STRATEGY 4 – VALUE ADDING ENTERPRISES

The options were evaluated for local feasibility and their potential effectiveness in controlling groundwater and salinity within the Study Area during the Technical Workshop held in Moora (7th February, 2008).

Technical notes for six of these options that have not been commonly adopted in the area previously are provided in Appendix 1.

The options that are identified as 'high' for feasibility and effectiveness will not necessarily be effective in all locations. Site evaluation is essential prior to implementation.

B.1.1 Key Management Actions

From this assessment, the options that are most likely to be effective for controlling groundwater and salinity in the Koojan Gillingarra Study Area are:

Option **Adoption Comment**

Integrated Graded Drainage	Not suited to all landscapes especially where there is deeper sand or laterite cap rock. There also needs to be suitable disposal sites (e.g. dams) which may not be easily located in the Capitella soil landscape unit. This option will have greatest benefit in controlling surface flows to the east flowing tributaries of the Moore River floodplain and on the Ranfurly unit. Adoption of minimum tillage practices is proving effective in reducing surface water run-off.
Pumping	There is local experience with groundwater pumping on farms. Using this experience, there are opportunities to demonstrate site assessment processes (e.g. drilling, pump tests and possibly geophysics) as well as installation of a single pump or a set field of pumps. Pumping groundwater to reduce the water table and salinity will have best application to areas with unconfined Surficial aquifers (e.g. Key Sites #1, 2 & 3). The key issue is safe disposal of water which may prove difficult at these sites. Pumping groundwater is an option to be considered at Key Site # 4 ('Brewers Lake') however detailed site investigation is needed to establish the groundwater aquifer systems that are causing the problems. Pumping is expensive (installation costs and ongoing power and maintenance costs). A cost/benefit assessment is needed for each site prior to adopting pumping as an action. The value of the asset being protected or recovered needs to be greater than the long term cost. Groundwater pumping other than for stock and domestic supply from Surficial aquifers within the Gingin Groundwater Area will require a license.
Siphons	The use of siphons is relatively new in WA but is proving to be effective in some areas. Their application may be suitable at Key Sites # 2 & 3 where there is sufficient landscape elevation for siphons to flow. Siphons require specific site design criteria so site assessment is essential. If a site is suitable, it is recommended that a series of siphons (perhaps 3-6) are installed. Safe disposal of discharge water is required.
Lucerne and other perennial species	Establishment of perennial pastures is an increasing component of farming systems relevant to the Study Area. There is considerable knowledge and experience within the area and with the adjacent West Koojan Gillingarra CDI project. The Northern Agricultural Region has leading farming systems industry initiatives with leading knowledge about perennial pastures. These include '*Evergreen Farming*' and '*Grain & Graze*'. Networking with these initiatives will provide relevant knowledge and support. The effectiveness of perennial pastures to control recharge causing groundwater rise and salinity is limited to their

	ability to use soil water. If grazed heavily (so 'leaf area' is minimal), their water use potential is not high.
Farm plantations (pine, other)	Commercial pine plantations within the area are now very common. These and other proven long-rotation tree crops are the most effective control of surface aquifer systems. The Barrett's have trialled a local provenance of Manna 'Gum' (*Acacia microbotria*) on poor deep sands with under-planting of Sandalwood to find an initial high level of biomass production. While not measured, the water use of this tree crop is undoubtedly high.
Fodder value – tagasaste, acacias	The use of tagasaste as a fodder shrub is well established within the area. There has been some trial and use of other fodder crops that have high water use potential. There is considerable expertise about these options locally and within the region.
Brushwood (*Melaleuca uncinata*)	While the current market for brushwood products is limited, it is a naturally occurring WA perennial species that can be established in waterlogged areas.
Granite/bedrock scree	Recharge to groundwater occurs across landscapes where ever there is no discharge. However, recharge is greater where there are shallow soils associated with fragmented rock outcropping. This occurs commonly on hill crests within the Study Area. Some of these areas have remnant natural vegetation. There is a need to ensure this vegetation is protected from grazing and able to regenerate. This may require additional effort to control pest (e.g. rabbits) and native grazers.
Spillway sand plantings	Spillway sands are described in Section A.1 for Site#6. These are transmissive soils located in minor valley floors where water accumulates. These areas are commonly not productive for agriculture but are well suited for revegetation.
'Break of slope' plantings	The 'Break of Slope' landscape situation is particularly significant where the Capitella soil landscape unit joins the Ranfurly unit (i.e. the transition from the sandy slopes to the alluvial soils of the Moore River floodplain). Revegetation of these locations is effective as they are a site of water accumulation in the landscape. Demonstration of effective 'break of slope' revegetation exists on McKinleys property along Barberton West Road.

Table B1 provides an assessment of the feasibility and effectiveness of the management options considered relevant to the Study Area. Table B2 lists strategies and actions for knowledge development, planning and adoption of proposed actions.

Table B1 Local Action Response Assessment

Management Options	Feasibility (H, M, L)	Effectiveness (H, M, L)	Comments
STRATEGY 1 – INTEGRATED WATER MANAGEMENT			
Surface Water Control			
Integrated Graded Drainage	H	H	• Generally low runoff in the catchment however should be effective in lower slopes.
Broad based banks	L		
Artificial waterways	H	M	• Demonstrated locally for Ranfurly unit, generally not suitable for unstable sandy soils.
Groundwater Discharge Enhancement			
Deep drains (closed and open)	M	?	• Variable responses in different soils and landforms, • Requires safe and acceptable disposal.
Pumping	H	H	• Requires safe and acceptable disposal. • Potential options for irrigation from superficial aquifers
Siphons	H	H	• Depends on elevation and safe disposal, • Sites high in the landscape may be suitable.
Slotted pipe	H	H	• Relevant experience within the Study Area, • More suitable for Ranfurly unit (Moore River floodplain). • Potentially expensive • Slots may become blocked and require occasional maintenance.
Evaporation and detention basins	L	L	• Relatively low evaporation rates in this area.
Waterways Management			
Flow continuity - including removal of channel obstructions (debris) and appropriate culvert and floodway design.	L	L	• Not relevant in the key sites of the Study Area. • Some application to tributaries discharging to the floodplain of the Moore River
Sediment control – including riffles and sediment traps.	L	L	• While sedimentation of the Moore River is occurring, sediment control in the river or tributaries will not reduce rising water tables or salinity.
STRATEGY 2 – PLANT BASED MANAGEMENT			
Perennial & Annual Pastures			
Lucerne and other perennial species	H	M	• Broad range of perennial pastures suitable to this area. • Limits to the effectiveness of perennials in groundwater recharge reduction.

Management Options	Feasibility (H, M, L)	Effectiveness (H, M, L)	Comments
			• The efficiency of groundwater use depends upon how perennials are managed. • Perennial pastures are a more flexible land use than trees or fodder shrubs.
Trees with commercial opportunities			
Farm plantations (pine, other)	H	H	• Very effective in Study Area. Currently available through commercial arrangements.
Oil mallees	M	L	• More suited to lower rainfall areas. • Other profitable farm forestry option available.
Tree belts	H	H	• Currently adopted in Study Area.
Sandalwood	L?	?	• Currently established effectively in the areas. • Opportunities for advice through FPC or other farm forestry organisations.
Wide-space sawlog timber	H	H	• Trials required to demonstrate suitable options.
Fodder value – tagasaste, acacias	H	H	• Previously established and used effectively in the area.
Brushwood (*Melaleuca uncinata*)	H	H	• Existing brushwood project in the area.
High Recharge Area Revegetation			
Granite/bedrock scree	H	H	• Map soils to identify high recharge areas (e.g. laterite hill crests), • Further information required on effectiveness of managing these areas.
Water accumulating site revegetation			
Spillway sand plantings	H	H	• Suitable on highly transmissive valley sands.
'Break of slope' plantings	H	H	• Suitable for these water accumulating sites.
Trees with biodiversity and amenity values			
Extended natural road/ rail reserve vegetation	L	L	• Better manage existing vegetation in reserves and remnant vegetation
Salt-land shrubs and pastures			
Salt bush	H	M	• Associated pasture regeneration provides groundcover that reduced evaporation at the site.
Irrigation			
Crops	H	H	• Options to be assessed.
Pastures	H	H	• Options to be assessed, including lucerne.
Horticulture	H	H	• Options to be assessed.
STRATEGY 3 – SOIL MANAGEMENT			

Management Options	Feasibility (H, M, L)	Effectiveness (H, M, L)	Comments
Minimum tillage and soil ameliorants).	H	M	• Reduced tillage can reduce surface run-off although may have little influence on rising groundwater, • Opportunities to reduce water repellence and increase moisture holding capacity (e.g. by claying),
STRATEGY 4 – VALUE ADDING ENTERPRISES			
Water Harvesting –			
Farm and domestic supply	L	L	• Suitability for storage in the area limited. •

Note: H = high, M = medium, L = low

Table B2 Knowledge, Planning and Adoption Assessment

Management Options	Comments
STRATEGY 5 – PLANNING	
Integrated Water Management Planning (tributaries).	• Effective for surface water management. Arrangements available through DAFWA.
STRATEGY 6 – CAPACITY BUILDING	
Skills development (bus tours, workshops, seminar attendance).	• Opportunities to increase knowledge and information sharing (e.g. for soil management).
Group development (annual 'update' meeting)	• Effective group structure required for coordinated action.
STRATEGY 7 – MONITORING & EVALUATION	
Monitoring Wells	• Opportunities exist for coordinated groundwater monitoring within the area using existing monitoring wells. • Strategic approach required to establish additional groundwater monitoring (e.g. at

	'Brewers Lake' and for the Capitella/Koojan Pool roads area).
STRATEGY 8 – INFORMATION MANAGEMENT	
GIS services (storage and retrieval).	• **Spatial information management is beneficial for future planning,** • **GIS capability required to be linked to water balance modelling.**
STRATEGY 9 – COMMUNICATIONS	
Signs, printed materials	• Strategic approach required to ensure linkage between management information relevant to the areas and adoption of practice change.
STRATEGY 10 – RESEARCH & DEVELOPMENT	
Groundwater investigations (drilling)	• Deep Monitoring wells to be installed by DAFWA in 2008 for future FPC pine plantations within the area. done in 2008. These will contribute to knowledge and understanding of groundwater trends in the area. • Knowledge developed about groundwater flow systems in the Koojan Gillingarra area (e.g. surface expression of the Leederville aquifer) may not have relevance in other areas within the Moore River Catchment (i.e. information is not transferable to other areas).
Geophysical survey	• Suitable to assist in understanding of sub-surface geological structures and salt load distribution although not essential for management of rising groundwater in most situations, • Would be useful to understand influence of Leederville aquifer on rising groundwater in association with investigatory drilling (e.g. at 'Brewers Lake'). • Curtin University (Contact: Rhett Harris) has capacity to advise on required methods.
Groundwater modelling	• A detailed Digital Elevation Model (DEM) is required for catchment water modelling. Note that the 'Land Monitor' project information is not sufficiently detailed to show areas of internal drainage within the Study Area. • Required for the Study Area to establish level of land use change for acceptable catchment water balance.

B.1.2 The potential for commercial use of groundwater

There is significant interest by landholders within the Koojan Gillingarra Study Area about the potential for commercial use of groundwater. This interest has been increased by knowledge about the rate of rise of all groundwater aquifers (including the deeper Leederville aquifer) and an expectation that lowering the level of these aquifers could provided the added benefits of reduced waterlogging and salinity risk.

Kay (1999) notes that a limited supply of fresh to brackish groundwater is available within the surficial and Poison Hill aquifers, with supplies of 10 to $40m^3$/day common. Numerous farm bores, wells and soaks currently utilise this readily available water supply.

Under the interim Gingin Sub-regional groundwater allocation strategy (WRC, 2002), abstraction from these aquifers without a license is limited to 1,500 kL/year. A larger volume can be abstracted under licence however it is interesting to note that there are currently no allocations from these aquifers made under license within the Study Area. This probably indicates there to be insufficient yield for commercial use.

There is further interest in use of the Leederville aquifer. Under current arrangements, this aquifer is fully allocated and no further abstraction is available. Kay (1999) notes rise in this aquifer and that it may be near the ground surface relatively soon in the 'Capitella/Koojan Pool roads' area. This area is where salinity of the Leederville aquifer within the Study Area is least (as shown on Map 4).

The potential for commercial use of groundwater from the Leederville aquifer from this location to reduce the risk of groundwater rise and salinity needs to be recognised. Licensing arrangements for this to occur will require consideration by the Department of Water as it would exceed the current Sub-area water allocation from this aquifer.

B.1.3 Actions for Adoption

Table B2 provides assessment of an additional set of strategies that relate to process of adoption. They are:

STRATEGY 5 – PLANNING

STRATEGY 6 – CAPACITY BUILDING

STRATEGY 7 – MONITORING & EVALUATION

STRATEGY 8 – INFORMATION MANAGEMENT

STRATEGY 9 – COMMUNICATIONS

STRATEGY 10 – RESEARCH & DEVELOPMENT

Key actions to be considered for the Koojan Gillingarra Study Area are listed below.

Option	Adoption Comment
Integrated Water Management Planning (tributaries).	Planning for surface water management is essential. This should occur at a property scale and link with neighbours where required. Planning for surface water control is a priority for the east flowing tributaries that discharge to the Moore River floodplain. Continuity of flow from lower slopes to safe disposal in the river should be included.
Groundwater investigations (drilling)	All options to drain, pump or siphon water to control groundwater tables and salinity require prior groundwater investigations. This may take some time to with monitoring to establish the aquifer that is to be accessed, and the potential yield.
Geophysical survey	Carefully designed geophysical survey can provide additional information for site investigations. Otherwise, geophysical surveys provide information to add to the understanding of groundwater processes. This would be useful especially for understanding the processes occurring at Key Site #4 ('Brewers Lake') and also for knowledge about the Yarra Yarra Palaeodrainage that occurs within the Moore River Floodplain.
Digital Elevation Model	A detailed DEM will provide increased understanding of the land surface elevation. The most detailed DEM currently available is at 2 meter contour interval. Even this level of detail is insufficient to show areas of internal drainage. A DEM will provide the basis for groundwater modelling.
Groundwater and water use modelling	Preparing a simple model of catchment water balance and using this for changing land use options is potentially the most effective tool relevant to the area for decisions about the extent to which land use change is required to control groundwater rise and salinity. This applies especially to the extent of tree crops.
Monitoring groundwater	Considering the high level of concern about the potential for groundwater to rise further and for salinity to occur, there is a need for a carefully planned strategic approach to groundwater monitoring. This should be based on existing monitoring wells and those proposed for construction to monitor the effects of commercial tree plantations. Additional monitoring wells may be required for critical areas (e.g. the Capitella/Koojan Pool roads location).

Adoption of all actions to control groundwater should be taken within a deliberate 'practice change' framework that includes:

- Information and knowledge management,
- Innovation, trial and demonstration,
- Ongoing planned group development and capacity building processes,
- Networking with other groups and industry initiatives, and
- Adapting to change and new knowledge.

A co-ordinated approach to adoption of well-demonstrated methods of controlling groundwater and salinity is most effective.

Attention has been drawn locally to the importance of pest management, particularly rabbits, to ensure viability of revegetation projects (R Barrett, *pers. comm.*). Pest and weed management is an essential component of site planning.

B.2 Selecting the areas

Identifying where in the landscape to adopt actions to reduce groundwater and salinity risk requires site investigations and planning, as outlined in Section B.1.

Priorities for implementation are identified below.

B.2.1 East-flowing tributaries discharging to the Moore River floodplain

Each of the east-flowing tributaries needs to be assessed for potential to cause localised flooding and groundwater recharge on the Moore River floodplain.

Site #5 (Airstrip Road) is the major tributary that is salt-affected in the upper reaches. A planned approach to integrated surface water management (within the catchment and on the floodplain), strategic revegetation in water accumulating sites and salt bush establishment in salt-affected areas will provide demonstration to implementation in other areas.

B.2.2 Aquifer recharge management

The most effective aquifer recharge management is occurring through establishment of commercial tree crops. For most beneficial effect to reduce groundwater rise and salinity, these should be located with priority in key water accumulating sites:

- Spillway sands (Site #6), and

- Break-of-slope (as occurs between the Capitella and Ranfurly soil landscape units).

Some of these sites may not be suited to Pines (*Pinus maritima*). Other commercial species could be considered (e.g. Brushwood).

Key Site #1 (Wandawallah Lake) provides a suitable situation to demonstrated the benefit of recharge management through commercial tree plantations. A considerable area is established to plantations now. A groundwater model (see Section B.3) should be applied to estimate the percentage of this internally draining catchment that needs to be permanently established with trees to lower water tables and achieve and acceptable water balance (note that completely drying out the lake may not be acceptable locally however reduction in the risk to Wandawallah Road is required).

Remnant natural vegetation on lateritic (gravely) hill crests should be protected by fencing to control grazing and enable regeneration to reduced groundwater recharge.

B.2.3 Aquifer discharge management

Enhancing groundwater discharge to lower groundwater levels using pumps, siphons or drains can be effective although not in all situations. Individual site assessment is essential.

Key Sites #2 (Banksia Woodland) & #3 (Pine Plantation) are best suited to trial the use of pumps and possibly siphons. Piped discharge to a waterway downstream from the existing farm water supply may be required.

All discharge enhancement options should be evaluated following site investigations for Key Site #4 (Brewers Lake).

Under *Soil and Land Conservation Regulations, 1992,* all proposed works to pump, drain or siphon groundwater require notification to the Commissioner of Soil and Land Conservation 90 days prior to water being discharged from these works. The procedure to notify the Commissioner is available from the Department of Agriculture and Food, WA.

B.3 Working out the balance

Local concern is clearly expressed about getting the balance between having adequate adoption of actions to make a difference to groundwater rise and salinity risk, and avoiding excess water use resulting on loss of valuable farm water supplies. This applies primarily to commercial or other tree plantations.

Quantifying the required extent for implementation of actions should be based on catchment water balance modelling. This is beyond the scope of this current study.

The steps required to set up a water balance model for the Study Area include:

1. Prepare a Digital Elevation Model (DEM) based on a regional geographic system (GIS). The 'Land Monitor' project provides information suitable for development of a DEM,
2. Obtain standard ('book value') plant water use information for key option (e.g. available through DAFWA for use in the one-dimensional model *AgET* developed to compare land use options),
3. Plan for additional groundwater investigations (e.g. drilling and geophysical investigations that could be undertaken at Key Site #4 ('Brewers Lake') and the Capitella/Koojan Pool roads area), and
4. Arrange for development of catchment water balance model with suitable service provider (e.g. CSIRO, private hydrologists).

The questions to be addressed by catchment water balance modelling are:

1. To what extent will high water-tables (i.e. within 2.0 m of the ground surface) occur within the Capitella and Rowes Soil Landscape units of the Study Area? (i.e. not applied to the floodplain - the Ranfurly unit),
2. Where is this equilibrium-state high water table most likely to occur?
3. When is this equilibrium-state high water table most likely to occur?
4. What optimal area (for each identified hydrological unit – sub-catchment or internal drainage basin) of deep-rooted perennial vegetation is required to maintain current conditions (i.e. no further increase in waterlogging and groundwater discharge)?
5. What is the impact on surficial aquifer groundwater resources if the level of deep-rooted perennial vegetation exceeds the optimal area (calculated in 10% interval, 10% greater, 20% greater etc.),
6. What volume of sustainable yield is available for irrigation within each identified hydrological unit (sub-catchment or internal drainage basin) of the Capitella and Rowes Soil Landscape units within the Study Area?

Development of a catchment water balance model for the Koojan Gillingarra Study Area is a recommended priority action considering the high level of commercial tree plantations and also the high value of groundwater resources.

IMPLEMENTATION SCHEDULE

Proposed Project	Suggested Actions	5-year Investment Period	Indicative Cost Allocation ($)	Contacts
1. Leederville aquifer drilling investigation.	1.1 Site assessment and drilling at Key Site # 1 (Brewers Lake).	Year 1	5,000	Phil Commander (DoW), Russel Speed (DAFWA).
	1.2 Site assessment and drilling in the Capitella valley	Year 1	10,000	
	1.3 On-going site monitoring (linked to other Leederville aquifer monitoring).	On-going	NRMO	
2. Perennial vegetation inventory and spatial information database	2.1 Arrange GIS spatial information database for Study Area	Year 1	5,000	Forest Products Commission
	2.2 Prepare an inventory of existing perennial vegetation (area, location, age) including natural vegetation (air photos), commercial farm forestry (FPC, landholders) and private farm plantings (farmer survey).	Year 1	NRMO	
3. Digital Elevation Model	3.1 Arrange information from 'Land Monitor' project	Year 1		Paul Findlater (DAFWA)
	3.2 Prepare detailed DEM suitable for catchment water balance modelling	Year 1	5,000	

4. Catchment water balance modelling	4.1 Prepare 'Contract Brief' for service provision.	Year 1		Russell Speed (DAFWA)
	4.2 Arrange contract service provision.	Year 1	20,000	
5. Floodplain geophysical survey	5.1 Arrange 'technical advisory group' meeting to derive 'Contract Brief' (based on assessment of near surface and palaeodrainage parameters of the Ranfurly soil landscape unit).	Year 1		Paul Findlater (DAFWA) Russell Speed (DAFWA) Paul Wilkes (Curtin University)
	5.2 Arrange contract service provision.	Year 2	40,000	
6. Surficial aquifer monitoring	6.1 Prepare spatial database with existing surficial aquifer monitoring (from T. Kay thesis)	Year 1	NRMO	
	6.2 Select key monitoring points based on catchment water balance model	Year 2	NRMO	
	6.3 Install observation well network	Year 1 and 2	15,000	
	6.4 Arrange on-going quarterly monitoring and reporting	On-going	NRMO	
7. Demonstration A – integrated surface water control	7.1 Select site for demonstration of integrated surface water control linking east-flowing sub-catchment with the Moore River floodplain and river channel.	Year 1		
	7.2 Prepare technical plan for demonstration site.	Year 1	3,000	Martin Keene (DAFWA) Noel Dodd
	7.3 Implement actions of demonstration site.	Year 2	30,000	
8. Demonstration B – groundwater pumping	8.1 Select sites and undertake feasibility assessment for groundwater	Year 1	2,000	Glenice Batchelor (Wallatin/O-Brien CDI)

and siphons	pumping/siphoning and associated disposal			
	8.2 Prepare technical plan for demonstration site.	Year 1	5,000	
	8.3 Implement actions of demonstration site.	Year 2	30,000	
9. Demonstration C – spillway sand revegetation	9.1 Select suitable site and prepare plan to demonstrate spillway sand revegetation.	Year 1	NRMO	
	9.2 Implement actions of demonstration site.	Year 1	10,000	
10. Demonstration D – 'Break-of-Slope' revegetation	10.1 Select suitable site and prepare plan to demonstrate 'Break-of-Slope' revegetation.	Year 1	NRMO	
	10.2 Implement actions of demonstration site.	Year 1	10,000	
11. Demonstration E – Hill-crest vegetation rehabilitation	11.1 Select suitable site and prepare plan to demonstrate hill-crest vegetation rehabilitation.	Year 1	NRMO	
	11.2 Implement actions of demonstration site.	Year 1	10,000	
12. Demonstration F – long rotation saw log plantations	12.1 Select suitable site and prepare plan to demonstrate spillway sand revegetation.	Year 1	NRMO	FPC
	12.2 Implement actions of demonstration site.	Year 2	10,000	
13. Roll-out program – from demonstrations A-F	13.1 Prepare cost-share arrangement guidelines.	Year 2	NRMO	
	13.2 Arrange 'roll-out' program.	Year 3-5		
			200,000	

14. Roll-out program – perennial shrubs and pastures	14.1 Prepare cost-share arrangement guidelines	Year 2	NRMO	Bill Currans (NACC)
	14.2 Arrange 'roll-out' program	Year 3-5	50,000	Link to 'Target Investment Program' (TIP) Phil Barrett-Lennard (*Grain & Graze* program)
15. Communications and engagement for practice adoption.	15.1 Arrange communication and information materials based on modelling and demonstration sites.	Year 2	NRMO 5,000	
	15.2 Arrange participating landholder communication and engagement program.	On-going	NRMO	

CONCLUSIONS AND RECOMMENDATIONS

Concern about rising groundwater and the potential for further salinity impact within the Koojan Gillingarra Study Area is well founded. Water tables in both deep and shallow aquifers are rising. Predictions made by Tanya Kay that up to 20% of the area may be prone to waterlogging due to relatively fresh groundwater rise (Kay, 1999) almost 10 years ago may be proving to be correct.

There is sufficient information about groundwater systems within the Study Area to conclude that most groundwater rise being observed locally as surface expression of seepage water is due to change in the unconfined surficial aquifers.

Since clearing the land of natural vegetation for agriculture 30-50 years ago, groundwater recharge rates have increased from approximately 5-10% up to about 30% of annual rainfall. The steady trend in annual average rainfall as measured by the Bureau of Meteorology is not consistent with local rainfall records kept by farmers within the area, and does not reflect the dry period over the last 5-7 years. However, rising groundwater is occurring as a result of the higher recharge that has cumulated over all years since clearing.

Measured rise in the deeper Leederville aquifer is also occurring. For most of the Study Area, this is confined by a thick layer of marine shale (Osborne/Kardinya shale). While the confining layer may be thin or fragmented in some locations, it provides significant separation between the two aquifers in most locations. Focus for management to address rising groundwater should be on managing recharge and discharge of the surficial aquifers.

The most effective management option for the surficial aquifers is commercial tree plantations. This is occurring extensively within the Study Area. The additional local concern is that an excessive area of tree plantations in the area may eventually cause valuable water resources (i.e. for farm and stock water) to decline. There is a need to develop a catchment water balance model as a planning tool for the area and initiate cooperative arrangements to ensure that current rapid land use change is beneficial but not detrimental to the natural resources of the catchment, including water supply assets.

Opportunities to reduce waterlogging and salinity risk while adding value to increasing water resources by irrigating crops and pastures is of increasing local interest. While water tables in the surficial aquifers are increasing, yield from these groundwater sources will remain limited and probably insufficient for significant commercial development. There may be some opportunities to develop small-scale irrigation projects however the costs and benefits of these enterprises require cautious evaluation. Depending upon the soil type and landscape position, there is the further potential of increasing salinity risk by irrigation. Site evaluation for irrigation proposals is essential.

The potential to utilise the increasing water resources in the Leederville aquifer is becoming evident for the 'Capitella/Koojan Pool roads' area. Pumping from this aquifer requires an allocation license. Under current arrangements, no further allocation is available for this sub-area of the Gingin groundwater region.

Recommended Actions

With the current understanding of groundwater processes in the Koojan Gillingarra Study Area, there is a range of actions that can be taken to address concerns about increasing groundwater and the risk of salinity.

1. Initiate integrated water management planning for the tributaries that discharge to the Moore River floodplain,
2. Arrange for development of a catchment water balance model that can be applied to identified sub-catchments of the Study Area (e.g. Key Site #1 – Wandawallah Lake),
3. Undertake groundwater investigations (drilling and possibly geophysical survey) for Key Site # 4 (Brewers Lake) and the Capitella/Koojan Pool roads area,
4. Liaise with the Department of Water to explore options to increase allocation of water from the Leederville aquifer (Capitella/Koojan Pool roads area) based on site investigations,
5. Seek support funding (e.g. through the NACC *Targeted Investment Program*) for extensive strategic revegetation of 'spillway sands' and 'break-of-slope' landscape positions,
6. Seek support funding (e.g. through the NACC *Targeted Investment Program*) for remnant vegetation protection and revegetation of high recharge hill crests,
7. Develop a set of 'demonstration sites' for site evaluation and trial of groundwater pumping and siphoning options (e.g. at Key Sites #2, #3 & #4),
8. Support local initiative and trial of long-term commercial tree options (e.g. *A. microbotria*, sandalwood, brushwood),
9. Arrange participation in industry-based initiatives for perennial pasture management and information sharing with the neighbouring West Koojan/Gillingarra CDI project,
10. Arrange group processes for landholder participation and engagement for targeted practice change outcomes.

Acronyms

CDI	Catchment Demonstration Initiative
DAFWA	Department of Agriculture and Food, WA
DoW	Department of Water
LAP	Local Area Plan
MCC	Moore Catchment Council Inc.
NACC	Northern Agricultural Catchment Council

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APPENDIX 1 Key Management option information

INTEGRATED WATER MANAGEMENT

➢ Surface Water Control

Management Option: Integrated Graded Drainage

Description
Earth structures constructed to intercept surface water run-off and sub-surface flow in duplex profile soils. The primary intent is to reduce soil erosion and waterlogging, however they also provide opportunities for water harvesting. In valley floor situations, reduced waterlogging and surface inundation should also reduce salinity risk.

The earth structures are built with a grader or bulldozer and constructed to discharge either directly into dams or waterways, or to artificially constructed waterways (Figure 2, WA Dept. Agric., 2002a). The two options most suitable to the Study Area are:

Grade Banks (WA Dept. Agric., 2002b)
Constructed with a flat base with a depth to clay on duplex soils (60-80cm) with a grade of 0.5-1.0% with soil deposition down slope to form an embankment. Banks are space 150-180 meters apart depending upon slope (Figure 1).

Figure 1. Grade bank construction.

Discharge from graded drainage is best integrated with dams for water harvesting or existing waterways. Otherwise, level sills can be constructed for safe dispersal although artificial waterways that integrate the banks with dams or waterways are preferred.

Key Design Criteria

- **Channel and bank specifications** (bank height, freeboard, channel width, channel depth, batter slope)
- **Channel gradient**
- **Bank spacing** – depends upon hill slope
- **Design capacity** – generally calculated for a 1-in-20, or a 1-in-10 Average Recurrence interval (ARI).

Feasibility

- **Grade Banks:** Well established practice. Benefits in waterlogging and associated salinity control.
  - Standard practices associated with water harvesting.
  - Valley floor surface water control will probably provide greatest salinity risk reduction by *in situ* recharge control.

Expected Benefits

- Reduced waterlogging and soil erosion.
- Reduced local flooding
- Some reduction in aquifer recharge, and reduction in salinity risk where ponding occurs in valley floor situations.

Potential Impacts

- Artificial waterways and broad-based banks may erode during construction and a period of stabilisation.
- Banks with insufficient grade may increase salinity risk.

Monitoring

- Assessment of waterlogging and local flooding control.

Source Information

WA Department of Agriculture (2002a) *Grassed Waterways* Misc. Publication 31/2002

WA Department of Agriculture (2002b) *Grade Drains* Misc. Publication 27/2002

WA Department of Agriculture (2003) *Broad-based Banks*. Farmnote 80/2003

Management Option: Groundwater Pumping

Description

Pumping from a single or multiple wells is used to lower groundwater tables. The depth of groundwater control can be greater than for deep drains but the area of influence is similarly dependent upon soil characteristics.

The proposed use of groundwater pumping is for the transmissive alluvial or fluvial sediments where there is water accumulation.

Site assessment should include groundwater yield assessment (pump test or other relative measure).

Submersible poly-piston design pumps are to be used with solar (Figure 1), wind (Figure 2) or electricity energy source. Some sites may require more that one production well.

A 125mm PVC production well is drilled to bedrock (or suitable aquifer depth) and screened for 50% of depth below a bentonite plug. Observation wells (50mm PVC) are to be installed to a depth of approximately 5 meters.

Discharge is to a detention basin or other safe disposal.

Figure 1. Solar powered groundwater pumping.

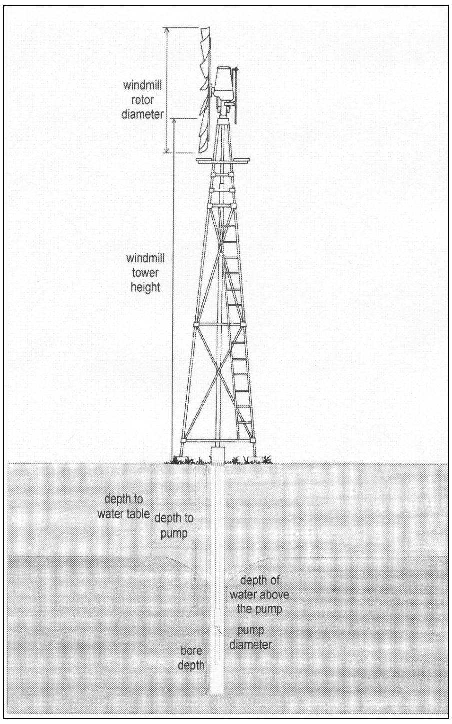

Figure 2. Example of a single well with a wind pump. (Source: SKM, 2001).

Key Design Criteria

- **Expected Flow rates:** to be determined by pump test.
- **Expected Pump Capacity:** up to 35KL/day (0.40 L/sec.) for 400W solar powered pumps and up to 76KL/day (0.88L/sec.) for 750W electricity powered pumps.

Feasibility

- Depends upon the depth, width and hydraulic gradient of alluvial/fluvial channels.

Expected Benefits

- Up to 500 m response (lower groundwater) in alluvial channels. The lateral response may be 100m. The area of 'recovery' could be 2-20 Ha although the more general benefit is considered to be salinity risk reduction.
- Private and public infrastructure protection (e.g. roads, rail, houses, sheds).
- Regeneration of natural vegetation (roadside verges and remnant patches).

Potential Impacts

- Disposal of discharge water if not contained within a detention pond or delivered to safe disposal.
- Return to high water levels if the pumps mal-function.

Monitoring

- Observation well transects (50, 100 and 200 m intervals).
- Evaluation of financial benefits using software packages (eg PUMPS).

Source Information

Campbell White and Associates. *Pumps – Manual Documentation.* Report prepared by Campbell White and Associates for the Department of Agriculture WA.

Carew-Hopins, D. (2003) *Groundwater Pumping to Evaporation Basins at Bodallin*. Paper presented at the 8th National Conference and Workshop on the Productive Use and Rehabilitation of Saline Land (PUR$L).

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Solar Energy Systems. *Windmill Pump Kit.* Promotional Brochure.

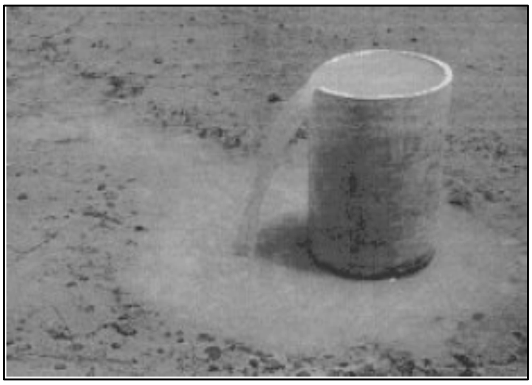
Wilson, Georgina (2001). *Groundwater Pumping is Proving its Worth: Nixon Case Study.* Salt – The Magazine of Australia's National Dryland Salinity Program, Issue 4 April 2001.

➢ Groundwater Discharge Enhancement

Management Option: Siphons

Description

Groundwater siphons can be used in hillside situations to lower water levels based on continuous flow piped to an outlet located lower than the expected depth of groundwater reduction (maximum depth of approximately 8 meters). No external energy source is required.



Production wells are drilled to a depth of 10-40 meters and lined with a 100mm screened casing. A 50mm internal casing is inserted and connected by an 'elbow' joint to discharge piping. A minimum flow of approximately 0.1L/sec is required (as indicated in Figure 1).

Figure 1. Artesian flow discharging at the rate of 8KL litres of groundwater per day (i.e. 0.09 L/sec). (Source: Seymour & George, 2001).

Critical flow rates (the rate required to prevent malfunction due to gas build-up in the pipeline) correspond to pie diameter (see Figure 3). Twin siphon discharge pipelines provide greater potential for continuous flow with low flow rates.

The area of influence corresponds to the flow rate (Figure 4). Figure 2 shows how multiple siphons can maximise drawdown. These could be connected or otherwise discharge independently.

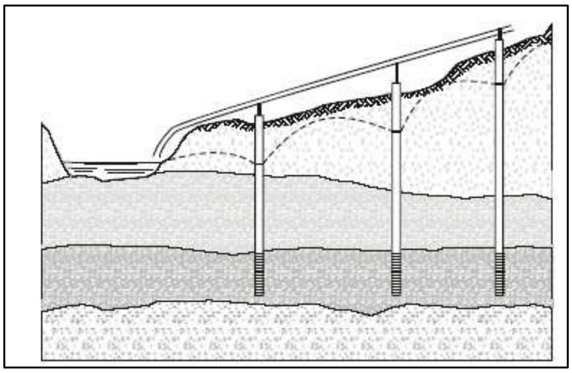


Figure 2. Several siphon wells can operate along a discharge area to reduce water levels and increase the area of maximum drawdown. (Source: Salama *et al.,* 2003).

Siphons could be installed in a grid format with spacing of approximately 150 meters (depending on site characteristics).

Key Design Criteria
(see also Seymour, 2002 – 'Bore Siphon Calculator')

- **Discharge pipe diameter:** generally greater than 25mm (see Figure 3)
- **Discharge gradient:** > 1.5% (2.5% is best) based on topographic height and length.
- **Discharge rate:** > 0.16 L/ sec (13.8KL/day)

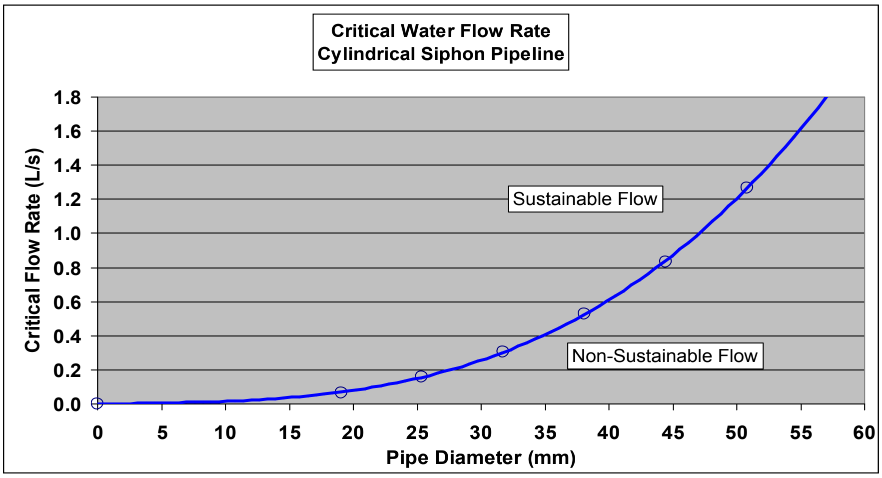


Figure 3. Critical flow rates necessary to sustain groundwater siphon flow. (Source: Seymour, 2002).

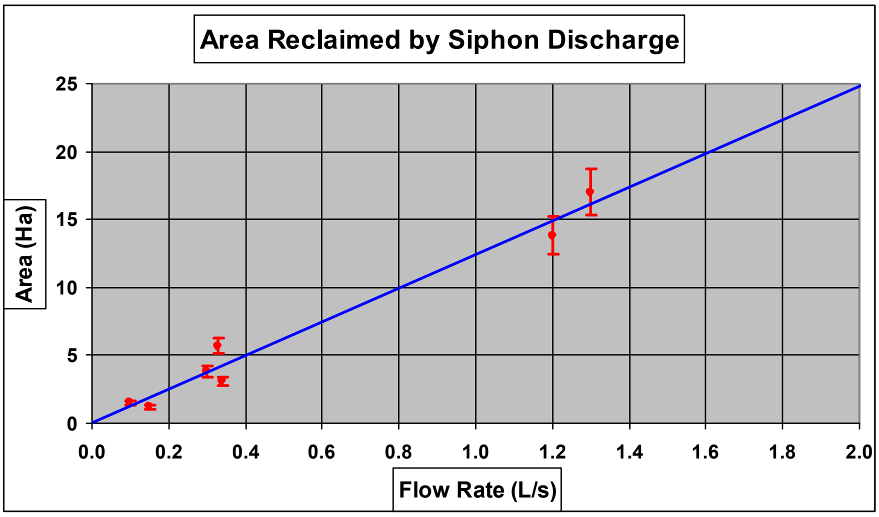


Figure 4. Siphon flow rate required to reclaim groundwater seepage areas. (Source: Seymour, 2002).

Feasibility

- Requires detailed site assessment. Correct installation is critical.
- 70% success rate should be best expected outcome.

Expected Benefits

- Could reclaim up to approximately 10 Ha salt-affected sites.
- Note: the siphons and discharge pipes are above ground (although pipes can be buried) so sites may not be suitable for cultivation.

Potential Impacts

- Siphon malfunctions will cause groundwater levels to rise to former levels.
- Disposal of discharge water if not contained within a detention pond or evaporation basin.

Monitoring

- Observation well transects (50, 100 and 200 m intervals).
- Evaluation of financial benefits using software packages (eg PUMPS).

Source Information

George, R. (2001). *Managing Saline Seeps with Siphons*. Farmnote No. 65/ 2004. Department of Agriculture, Perth.

Salama, R., Riasat, A., Pollock, D., Rutherford, J., and Baker, V. (2003). *Review of Relief Wells and Siphons to Reduce Groundwater Pressures and Water Levels in Discharge Areas to Manage Salinity*. A Report to Waters and Rivers Commission, WA. CSIRO Land and Water, Perth.

Seymour, A.J. (2002). *Bore Siphon Calculator*. Department of Agriculture, Katanning. Western Australia.

Seymour, A., and George, R. (2001). *Relief Wells in South Western Australia*. Farmnote No. 42/ 2001. Department of Agriculture, Perth.

Management Option: Sandalwood

Description

Sandalwood (*Santalum spicatum)* is a root hemi-parasitic plant, requiring a host species to survive. It can be grown with a range of locally-occurring host plant (*Acacia spp.* are most suitable).

Figure 1. Sandalwood *Santalum spicatum*. (Source: Forest Products Commission).

A stocking rate of between 200 and 300 sandalwood stems per hectare should yield between two and three tonnes of commercial grade sandalwood at 20 years in the above 400 mm annual rainfall zone.

In the less than 400 mm rainfall zone, it is expected this yield will be achieved in approximately 25 years. The current value of sandalwood approximately $4,000/tonne.

While sandalwood is slow growing, it does have potential to utilise groundwater, especially in association with host plants.

It is expected that sandalwood will be most suitable for recharge control on scree slopes adjacent to granite or other rock outcrops.

Figure 2. Sandalwood (*Santalum spicatum*) establishes in row plantings for a local provenance of 'Manna Wattle (Gum)' (*Acacia microbotria*) on Robin and Judy Barrett's property.

Figure 3. Sandalwood (*Santalum spicatum*) with host (Source: Forest Products Commission).

Feasibility

- The market exists and methods for establishment are developed.
- Difficult to establish where kangaroos/ rabbits have access. Fencing is required.

Expected Benefits

- Commercial products
- Groundwater control
- Increased biodiversity values.

Potential Impacts

- Cannot be grazed by stock until the plantation is aged 5-7 years.

Monitoring

- Observation wells for extent of groundwater control.

Source Information

Brand, J. and Jones, P. (1999) *Growing Sandalwood of farmland in Western Australia*. Sandalwood Information Sheet 1. Department of Conservation and Land Management, 4pp.

Jones, P (2002) *Estimating Return on Plantation Grown Sandalwood (Santalum spicatum).* Sandalwood Information Sheet. Issue 3. Forest Products Commission.

Service Providers

Avon Sandalwood Network Inc.

Forest Products Commission

Greening Australia (WA)

PLANT BASED MANAGEMENT….

➢ Trees with commercial opportunities

Management Option: Brushwood *(Melaleuca uncinata)*

Description

Brushwood (*Melaleuca uncinata* and related species) provides commercial products for urban fencing and shelter thatching. Estimated yields of approximately 10 tonnes/Ha could be expected at first harvest at around age 10 years. Subsequent harvest could be expected every 7-10 years.

Plants are tolerant of some waterlogging and salinity making them suitable for establishment in tree belts or blocks within mildly saline water receiving valley floor locations.

Figure 1 Brushwood (*Melaleuca uncinata*)

Figure 1 Brushwood fencing

Key Design Criteria

- Assessment of soil salinity
- Establish in belts or blocks
- Suitable for riparian zone rehabilitation.

Feasibility

- The market exists and methods for establishment are developed.

Monitoring

- Observation wells for extent of groundwater control.

Source Information

Robinson, C., Huxtable, D., Emmott, T. (2004) DRAFT Growing Melaleuca broombush for brush fencing on cleared farmland in southern WA

Maurice Barnes – grower experience at Trayning.

Service Providers

Greening Australia (WA) (sourcing suitable local provenance seed)

Chatfield's Nursery (Seedlings)

PLANT BASED MANAGEMENT….

➢ Salt-land Shrubs and Pastures

Management Option: Saltland Grazing

Description

Saltbush (*Atriplex spp.* and other plants) are forage plants suited to growing on saline land. They are also generally waterlogging tolerant.

Stands of saltbush are also capable of utilising up to 100mm of rainfall annually and as a result, improve soil water and salinity to allow additional pasture species to establish. The combination of shrubs and pastures provides valuable greed feed for the summer/autumn period.

Salt-affected areas can be established with complete cover by saltbush. Alternatively, saltbush can be established in rows with pasture or cropping between.

Some areas are best suited to natural regeneration of Bluebush (*Maireana brevifolia*). Only fencing is required for these areas.

Geophysical survey (EM31 and EM38 to map soil salinity) is recommended for species selection in relation to each site.

The 'Sustainable Grazing on Saline Lands' program is establishing a networked set of trial sites across the Wheatbelt. This provides a substantial opportunity for increased information and learning experience for the CDI program.

Figure 1 Valley floor salt bush planting

Key Design Criteria

- Soil salinity
- Access to fresh stock water

Feasibility

- Well developed establishment methods and understanding of nutritive values
- Profit margins dependent upon livestock management and commodity prices.
- Saltbush alleys: Allows continued cropping and increased livestock value on high risk areas.

Expected Benefits

- Productive use of saline land

- Increased biodiversity values

Monitoring

- Observation wells for groundwater monitoring
- Economic modelling for benefits to farming systems.

Source Information

Barrett-Lennard E. (2003) *Saltland pastures in Australia: a Practical Guide* Second Edition. Land, Water and Wool SGSL Sub-program.

Lloyd, M.(2001) *Profitable, Sustainable Saltland Pastures? Get Real!* Conference Proc. *Dealing with Salinity in Wheatbelt Valleys: Processes, prospects and practical options*. Merredin WA, July-August, 2001.

Sustainable Grazing on Saline Lands (2004) *Profitable and Sustainable grazing on Saline lands in Western Australia* Spring field walk notes, property of Tony, Donna and Simon York, Tammin, WA.