WARRENBAYNE BOHO
Land Protection Group Inc.

Groundwater levels in the Warrenbayne Boho Area 1982-2020

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Secretary – Warrenbayne Boho Land Protection Group Inc

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Disclaimer. This report contains general information for people with land in the Warrenbayne Boho Land Protection Group Inc. area. It is intended as an update on groundwater levels in the area and the effectiveness and persistence of treatment strategies adopted by group members since the 1980's. The report relies heavily on the Visualizing Victoria's Groundwater database and readers are directed to that website for information on the limitations of the database.

Contents

Summary

This review was undertaken for the management committee of the Warrenbayne Boho Land Protection Group Inc. and other landowners in the Warrenbayne and Boho areas. Its purpose was to provide general information on the salinity processes in the Warrenbayne Boho area, the current situation with watertables and the effectiveness of treatment strategies for high watertables and salinity.

The Visualizing Victoria's Groundwater database was the primary source of information for watertable levels and trends. The key findings were:

- On the lower slopes at a ground surface elevation of 215 to 185 m asl there is a slow rising trend in groundwater across the area. This suggests that current discharge areas may be expanding near the break of slope. At the northern extremity the rising trend may also be associated with a regional groundwater system north of the Hume Freeway. Further monitoring is needed to confirm this.
- In the upper Boho valley most bores have water levels that indicate they are in discharge zones and most have rising watertable trends. However, further monitoring is required to clarify the most recent trends in groundwater levels.
- In the upper Warrenbayne valley along the Warrenbayne and Robinson's Creeks the water levels in all bores have fallen and groundwater levels are probably more than 2.0 m below ground surface throughout the valleys. The falls may be due to reduced recharge in recent years associated with reduced rainfall and/or to tree planting on the valley floor. Further monitoring in the upper part of the valley would be useful to confirm this.
- In the upper slopes and high recharge areas (above 230 m asl) of the National Soil Conservation Program (NSCP) research site and around the Dobsons Rd hills in Warrenbayne bore water levels have fallen probably because of lower rainfall and hence lower recharge compared to before 1994. However, there is a possibility that tree planting and other revegetation strategies in high recharge areas have also reduced recharge. This has not impacted on the discharge zone in the NSCP research site and water levels have remained unchanged since the bores were installed.
- In comparison the forestry sites of the break of slope areas on the Dobsons Rd hills, the Harrison Rd catchment and Warrenbayne West, bore water levels have fallen substantially and groundwater levels are no longer at a height where the processes of salinity can continue. These falls are far greater than in other areas where the falls may only be due to reduced rainfall.

The treatment of high recharge areas by planting of trees, shrubs and grasses has been ineffective in halting the processes of salinity and broader scale treatment is needed if the problem is to be halted. The best surviving species in these plantations are listed. An alternative strategy of regeneration of native grassy woodlands is suggested which can be adopted across broader areas.

Break of slope forestry on the other hand appears to have lowered the watertable in several locations and the processes of salinity have been halted in a number of areas. The species that appear to be most suited to the break of slope (forestry) option and in some recharge areas are Radiata pine, southern blue gum, spotted gum, sugar gum, red iron bark, flooded gum, Sydney blue gum, river sheoak, silky oak and red gum.

Acknowledgements

The concept of this report has its origins in the Warrenbayne Boho Land Protection Group Inc. (WBLPG) report "Groundwater levels in the Warrenbayne Boho Area 1982-1991". A revision and expansion of the report to evaluate treatment strategies for high watertables was suggested by Jill Breadon (formerly from the Center for Land protection Research) and Professor Snow Barlow at a management committee meeting of the WBLPG in May 2019. Along with a substantial in kind contribution from the author the management committee of the WBLPG provided some cash funding to complete the review and publish the report.

The author acknowledges the following landowners in the Warrenbayne Boho areas who assisted the review: Alan and Carole Haslam, Jim Dalton, John Harrison, Debbie Hill, Steve and Karen Viant, Paul, Betty and Diane Schultz, Emmie de Fazio, Neil McPherson, Jean Miller, Snow Barlow, Ken Heywood, Kerri Robson, Marg Davis, Rebecca Cole and Janine Washusen (who helped with editing).

Brian Garrett who was instrumental in developing the salinity program for the Goulburn Broken Catchment in the late 1980's and 1990's kindly assisted by reviewing this report.

About the author

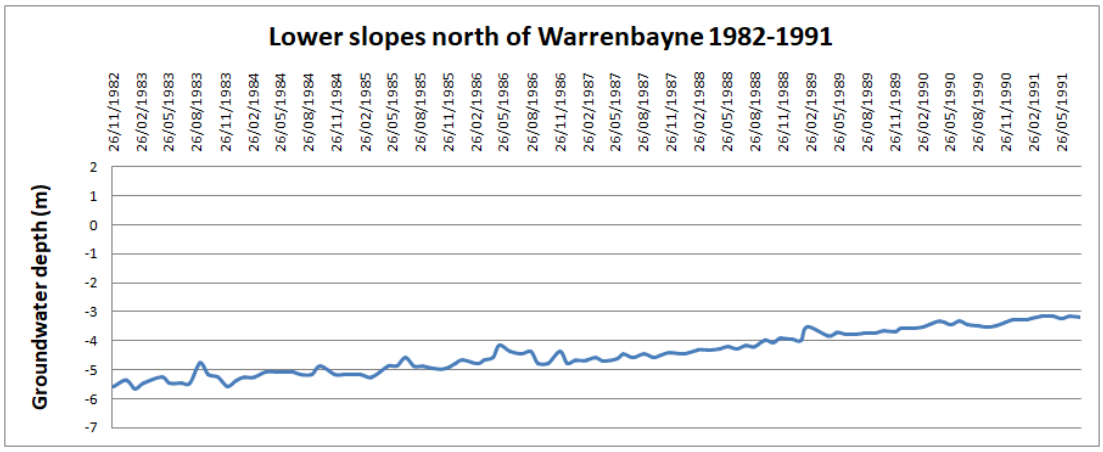
Russell Washusen has been a part time farmer in Warrenbayne and Warrenbayne West for 44 years and is the current secretary of the management committee of the Warrenbayne Boho Land Protection Group Inc (WBLPG). He has a PhD and MSC by research from the University of Melbourne and is a graduate in Agricultural Science from Dookie College. Russell spent much of his professional life with CSIRO as a research scientist and when he retired he was a Principal Research Scientist and Research Team Leader and he also held an Honorary Principal Fellowship (Associate Professor) with the University of Melbourne.

It was at Dookie in the early 1970's that Russell first learnt of the processes of salinity in the southern Murray Darling Basin. This started an association with salinity (not necessarily by choice but certainly because of where he farmed) that has followed him for almost 50 years. He first worked as a salinity research officer in the Goulburn Valley and later in Warrenbayne and Boho when he took over the onsite monitoring of the Centre for Land Protection Research projects which included the extensive groundwater and salinity monitoring networks; and also research into the effectiveness of revegetation strategies in recharge areas. It was during this time that Russell found there was an unexpected rise in watertables in the lower slopes that led to the publication in 1991 *"Groundwater Levels in the Warrenbayne Boho Area 1982-1991"* a review of which is the bases of this current report. With the Centre for Land Protection Research he went on to help expand the research bore network in 1992 and establish break of slope treatment strategies in the local area before plantation forestry research took him further afield. He has since worked as a research scientist right across Australia and overseas, much of his time spent in the two most challenging areas for salinity in Australia, the southern Murray Darling Basin and the southwest of Western Australia.

Russell has also helped to develop Victorian and regional catchment management strategies, often with salinity in mind. He is a past member of the Goulburn Broken Catchment and Land Protection Board leading up to the formation of the Goulburn Broken CMA and he represented the CMA on Plantations North East (Northeast Victorian Regional Plantations Committee) and the Benalla Mansfield and Northeast Forest Management Area Advisory Committee. He was also a member of the Victorian Private Forestry Council for several years.

Introduction

In 1991 the Warrebayne Boho Land Protection Group (WBLPG) with assistance from the Department of Natural Resources and Environment produced the publication "Groundwater Levels in the Warrenbayne Boho Area 1982-1991". This small book was the first attempt to bring the results of a comprehensive research program conducted in the area by the Centre for Land Protection Research to the attention of the local community and help guide development of treatment strategies for dryland salinity in Warrenbayne and Boho.



A key finding in 1991 was an unexpected persistent rise in the watertable in the lower slopes well away from the main recharge areas and further down slope from existing discharge sites. This bore is on Dobson's Rd, Warrenbayne, north of the Baddaginnie-Swanpool Rd.

The key findings in the 1991 report were: (i) An unexpected and persistent rise in watertable levels in the lower slopes well away from the main groundwater recharge areas and their associated discharge areas; (ii) the period of the investigation had above average rainfall and hence recharge into the groundwater system was probably higher than normal; and, (iii) simple modelling of rainfall trends indicated that the rise would probably continue into the future even in times of lower rainfall unless something was done to stop it.

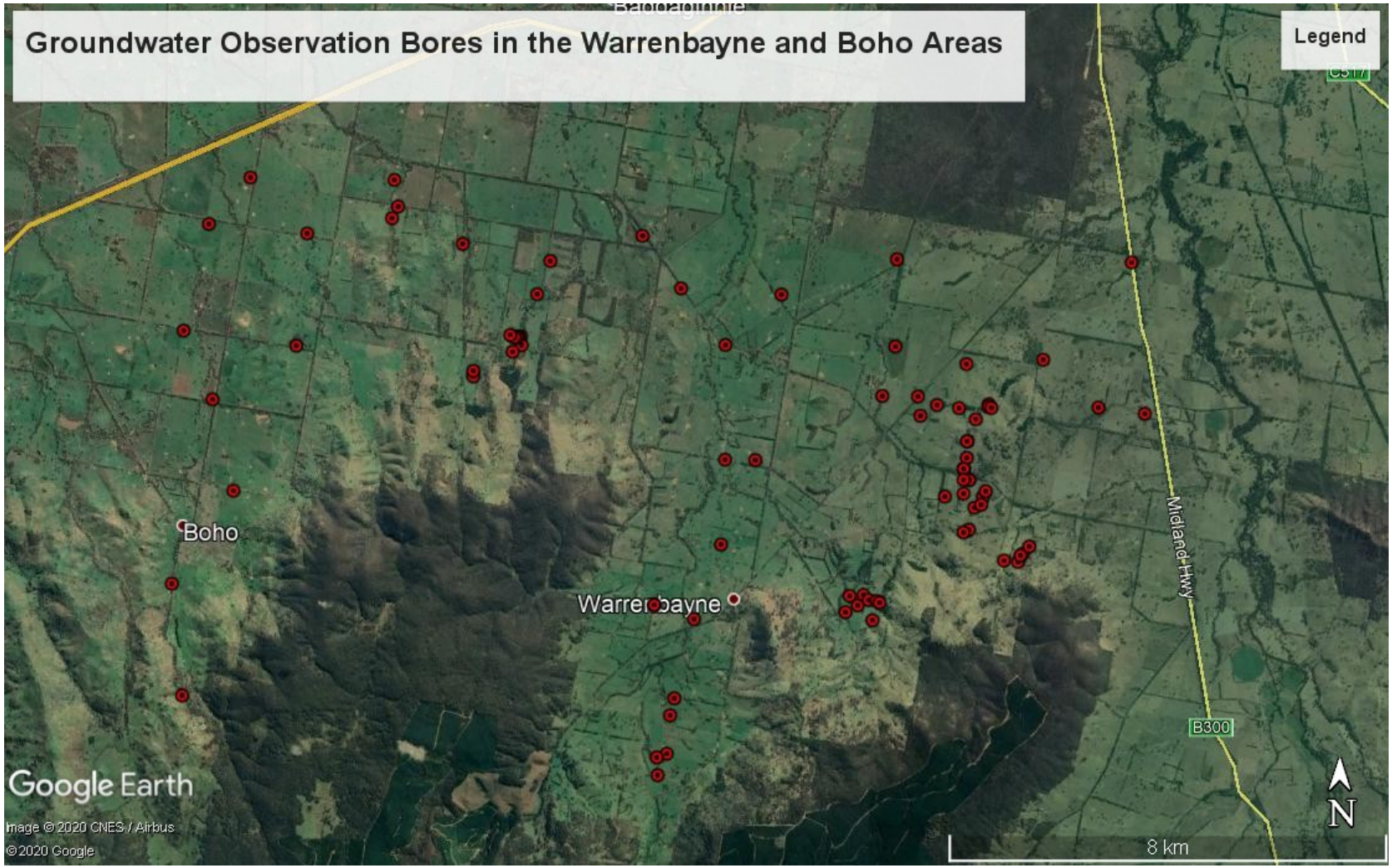
One of the outcomes of these findings was an expansion (starting in 1992) of the bore network to further investigate those areas not yet affected by dryland salinity in the lower slopes well away from the main recharge areas.

In the 29 years since 1991 there has been a fluctuation in rainfall. Firstly there was a long period with below average rainfall extending to about 2009, followed by a return to more or less normal rainfall patterns after 2009. With this longer history and fluctuating rainfall the WBLPG management committee thought it time to again review what has happened to watertables since bores were first installed in 1982 and get an update on what has happened in the expanded bore network.

The aims of this review

The aim of this review was partly to give the management committee of the WBLPG and other local land owners (old and new) an explanation of the processes at work that leads to increased watertable levels and salinity. Also to find out what has happened to watertables since the bore network was established, especially those bores established after 1991.

The WBLPG management committee also decided that a review of treatment strategies was overdue. For some years before 1991 and particularly since 1991 there have been many treatment strategies put in place in numerous locations around Warrenbayne and Boho. With the exception of an investigation into the potential to use the water for irrigation which was found to be unviable, most involved establishment of deep rooted plants (trees, shrubs and grasses) to use up water either before it enters the groundwater system in the higher rocky recharge areas or directly from the watertable in the lower slopes. This review will provide an appraisal of the successes and/or failures of these treatment strategies and the opportunities they present for the people of Warrenbayne and Boho.



The groundwater observation bore network in the Warrenbayne and Boho areas.

Locations mentioned in this report.

Dryland salinity - mechanisms

Dryland salinity a universal problem

Dryland salinity is not restricted to the Warrenbayne Boho area; it is a problem over large areas of Australia including local areas neighbouring Warrenbayne and Boho and more regionally across the southern Murray Darling Basin. It is also a considerable problem in other countries where the climate is conducive to dryland salinity. To give some idea of the scope of the problem in 1991 it was estimated that in excess of 600,000 hectares of land mainly in southwest Western Australia and southeastern Australia and 810,000 hectares in the U.S.A and Canada in the northern Great Plains were affected by dryland salinity.

In Australia dryland salinity is associated with rising groundwater levels which in relatively dry climates bring salts to the surface soils through a process of capillary action and evaporation. The worst affected areas erode badly and the less severely affected land has reduced pasture production. Discharged salt in saline surface water also enters rivers and streams to become a problem lower in the catchment - which for Warrenbayne and Boho is the lower areas of the southern Murray Darling Basin.

'Salt scald' where the top soil has eroded away. In some areas the degradation also takes the form of deep gully erosion.

Treated discharge sight with a watertable monitoring bore at centre. The water level in this bore with a few slight variations in level has been at or near the soil surface since 1985.

Groundwater recharge

Watertables are a natural phenomenon and they were present before land was converted from native grassy woodlands into grazing and cropping land. Rainfall in these natural woodlands did enter the groundwater system but only after some of the water was captured in foliage of trees, shrubs and grasses and evaporated back into the atmosphere. Much of the water that came to the ground was then held in leaf litter and other plant material in various stages of decay before the remainder entered the soil or became run off into rivers and streams. Water held in the soil was then exploited by the deep root systems of the native plants before any could 'recharge' the groundwater system. When native vegetation was replaced with shallow rooted crops and pastures simply more water became available to recharge the groundwater system (and more water became run off).

The importance of geology

The processes of salinity are complex and as varied as is geology. In many areas of Australia the groundwater systems are regional in scale. This is most notable in southwest Western Australia where recharge sometimes occurs many kilometres away from discharge or saline areas, as groundwater is often transported many kilometres along shear zones in the parent bed rock. The groundwater system in the Sheep Pen Creek area is another example. Here sedimentary rock is deeply weathered and cracked which allows groundwater to flow through the parent bed rock.

This is not the case in Warrenbayne and Boho and some neighbouring areas in nearby Tatong, Swanpool and Balmattum. These areas have an unusual geology with the parent rock being rhyodacite which in the Violet Town area geologists refer to as the Violet Town Volcanics. As the name suggests this is a volcanic rock derived from lava flows from volcanos in the Devonian period. In 1982 when the Centre for Land Protection Research first established their extensive network of research bores in Warrenbayne and Boho it was found that the rhyodacite bedrock was relatively unfractured, so much so that it was described by Dr Phil Dyson as "a massive crystalline rock structure". This rock forms a bottom or basement to the groundwater system preventing water from other areas and the local groundwater, from moving through it. This means the groundwater systems are localized and the discharge areas are very close to the recharge areas. Hence treatment strategies are needed on a local scale - which makes salinity treatment here far simpler than in areas like the southwest of Western Australia.

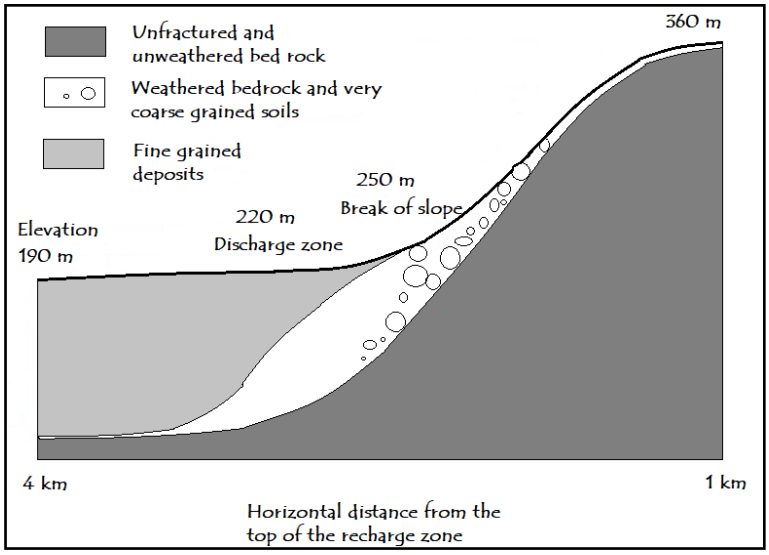
This situation is compounded by the type of material that has been deposited away from the hills. Here fine grained material and heavy clays have been deposited which also forms another barrier to groundwater flow (as we will see later water does move through this material - all be it very slowly). This material with the rhyodacite bedrock forms a kind of basin, sometimes referred to as a 'bath tub' by people trying to explain how it works. The basin or bath tub has been slowly filling with water that has entered the groundwater system from the recharge areas - and there is no outlet for this water except to discharge at the ground surface.

Location of recharge areas

Groundwater recharge areas are found throughout most of the Warrenbayne Boho area but the most important source of recharge is in the steep rocky hills. These areas have been designated "high recharge areas" for planning and treatment purposes. **(Note: The Warrenbayne Boho area has been mapped extensively by salinity specialists for treatment purposes into high, moderate and**

low recharge areas. These terms will be used from time to time throughout this report.) In high recharge areas the soils are derived from decomposing rock and are relatively course grained compared to soils lower in the system. The soils have low water holding capacity and without deep rooted native trees, shrubs and grasses, they reach a point of saturation quickly and water enters the groundwater system rapidly and in large amounts. Further down the slope and on to the lower slopes, the soils generally become progressively heavier and deeper and while recharge does occur it is much slower and involves smaller amounts of water.

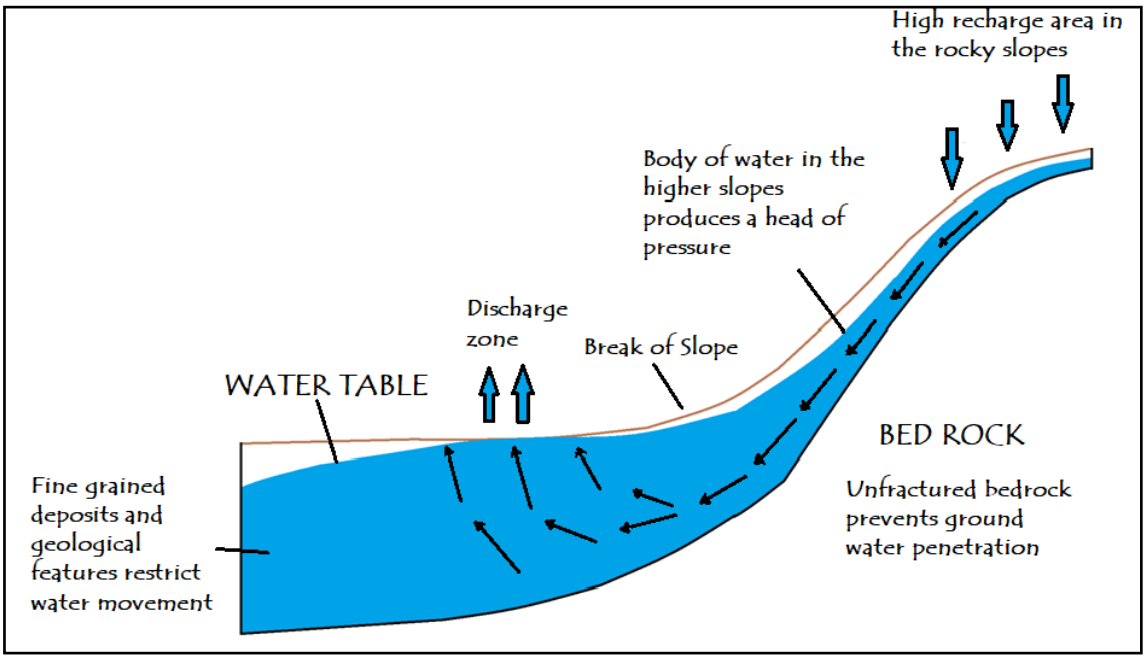
Rocky recharge area in Warrenbayne where water from rainfall rapidly enters the groundwater system once the soil has become saturated and precipitation exceeds evaporation: This usually occurs around the start of winter but can occur at any time when conditions are right.



Cross section through the Warrenbayne hills showing the three broad categories of geological materials that influence water movement: (i) The base is impermeable unfractured and unweathered bedrock; (ii) above that in the recharge areas is a layer of heavily weathered bed rock and coarse grained soils where water enters the groundwater system and moves comparatively rapidly down slope. This zone is derived from the weathering process of the bed rock – it becomes progressively finer grained and deeper down slope; (iii) and then, there is a relatively impermeable zone of very tight fine grained material away from the hills. With the unweatherd bed rock this material forms a basin that has been slowly filling with water from the recharge zones.

The significance of the "break of slope"

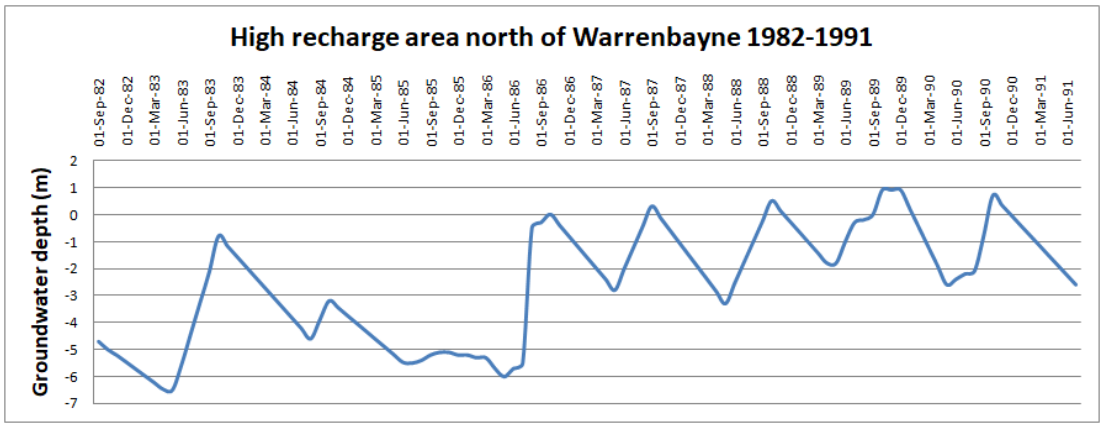
As the groundwater system fills and watertables rise the entire system develops a head of pressure because the groundwater movement down the slope above the parent bed rock slows substantially at the break of slope; and the pressure exerted from water held above the break of slope forces water vertically into the discharge sites. As we will see later this pressure may also be forcing groundwater further out onto the lower slopes well away from the main recharge areas.



Direction of groundwater flow from recharge areas to the break of slope: Groundwater movement is restricted at the break of slope because water movement slows as the gradient lessons. This phenomenon is common to other geologies where there is a change in slope, however in the case of Warrenbayne and Boho the relatively impermeable nature of the bedrock and the material deposited away from the hills also prevents water moving out of the system.

The movement in groundwater is reflected in the bore water levels that were established in 1982. The three hydrographs shown below have been taken from the 1991 report and depict: (i) A bore on the higher slopes near a high recharge area east of Dobson's Rd in Warrenbayne; (ii) one just below the break of slope in a discharge zone near School Rd in Boho; and, (iii) one on Dobson's Rd in Warrenbayne in the lower slopes below the discharge zone.

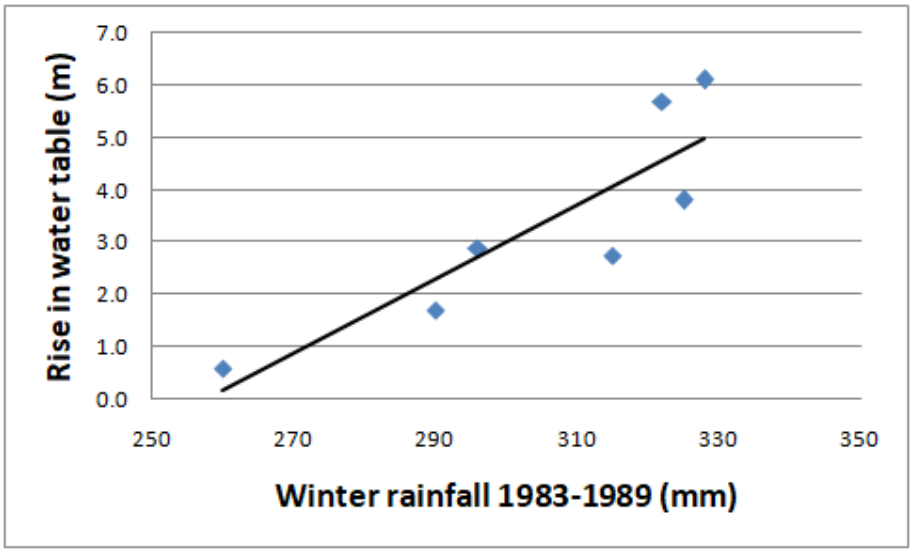
In the higher bore water levels fluctuate considerably. For example in 1983 the water level rose more than 5 metres. Each of these peaks reflects a period when recharge was occurring. Note that these peaks occurred in spring or early to mid summer, a few months after the recharge occurred in winter to early spring. This is typical of bores in these locations.



Bore from near the high recharge area east of Dobson's Rd in Warrenbayne showing seasonal fluctuations in the watertable height when recharge of the groundwater system occurs.

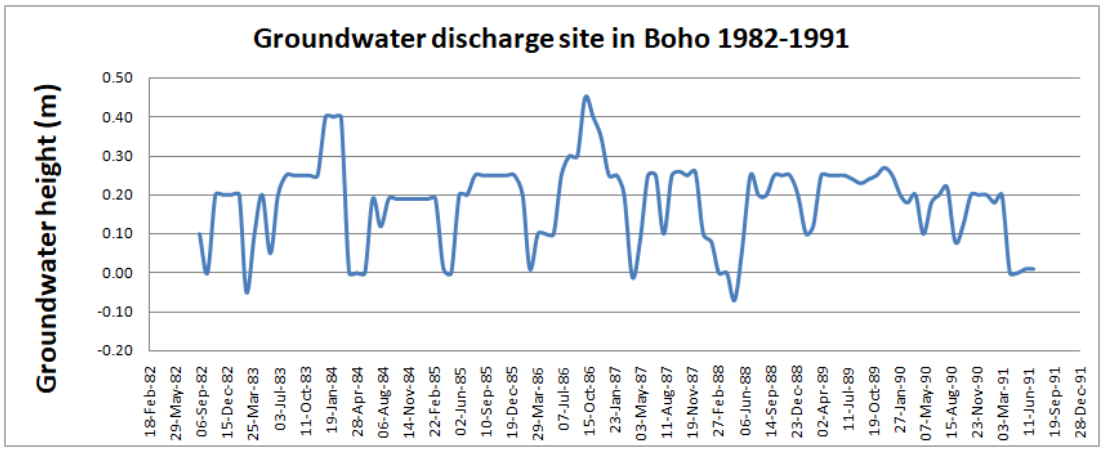
This bore has unusually large fluctuations probably because this area has low water storage capacity which has forced groundwater a long way up the bore and even above ground level each year between 1986-1990. In other words this site acts as both a recharge and discharge site – a common phenomenon observed around Warrenbayne and Boho near the break of slope or just above the break of slope in years with excessive recharge.

Again incidentally this bore shows just how closely associated recharge is to winter rainfall. Recharge occurs after the soil in the recharge areas has become saturated and when precipitation exceeds evaporation. This often occurs around May or June. The chart below plots the rise in the watertable recorded in this bore with the winter rainfall recorded for Warrenbayne at the Bureau of Meteorology rain gauge at Coramandel. The correlation is statistically significant.



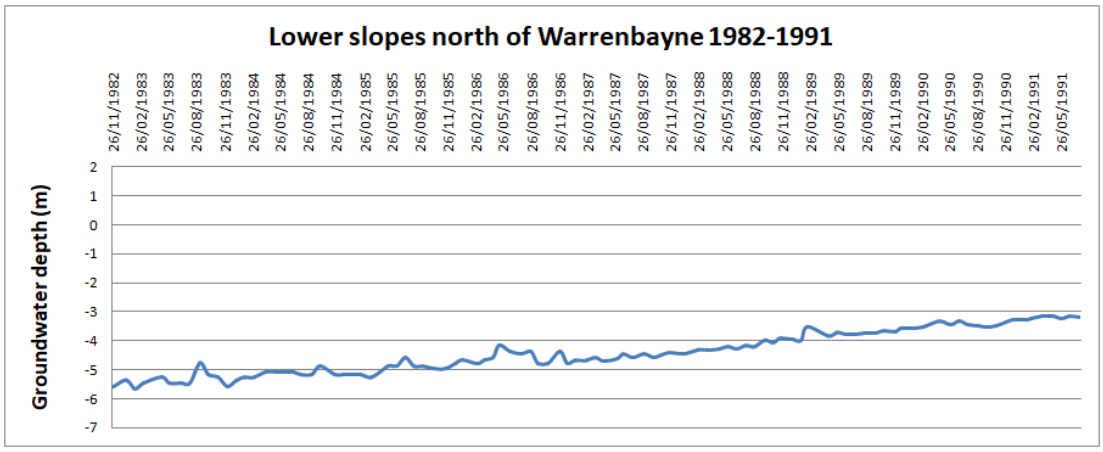
The relationship between the seasonal increase in watertable height in the above hydrograph and winter rainfall recorded at Coramandel in Warrenbayne.

The next hydrograph is in a discharge zone. The most significant thing that it shows is the effect of the pressure that results from slowing of water at the break of slope. Here the water level is mostly above the ground surface. This site is one of the worst saline areas in Warrenbayne and Boho.



Bore from the discharge area on School Rd, Boho showing the watertable was high enough to discharge water at the soil surface for most of the period between 1982 and 1991.

The last hydrograph is from a bore further down slope and almost 400 m to the northwest from the nearest discharge site. This trend shows that the pressure exerted at the break of slope is also forcing water towards the surface well away from the recharge areas and main discharge sites. In 1991 when this trend was discovered this type of behaviour was unexpected and it led to an expansion of the research bore network into the lower slopes in 1992 and a general expansion of the network into areas at the time unaffected by salinity.



Bore from the lower slopes on Dobson's Rd, Warrenbayne. This bore is located below a current discharge site showing a more or less continuous upward trend in the watertable level.

The pressure exerted at the break of slope produces another phenomenon. Discharge sites appear to occur first as an isolated outbreak apparently surrounded by unaffected land at the same elevation. This occurs because very hard layers can be found at various depths and water finds its way through weaknesses in these layers and at first only affects a localized area. One of the aspects of the research project set up by the Centre for Land Protection Research was to study groundwater behaviour in 2 or more bores at one location where these hard layers occurred. In these situations the water level often starts off at different depths but they eventually even out. Hence water will eventually find its way even through these hard layers (Dr Phil Dyson *personal communication*).

Factors affecting salt accumulation – water logging versus salinity

Rainfall

While most of Warrenbayne and Boho has the same basic geology, rainfall is far more diverse. At the top of the catchment approaching the Strathbogie Plateau to the east of Warrenbayne, the average annual rainfall can be almost twice that of areas to the west approaching Boho and Violet Town. Higher rainfall means potentially greater recharge but it is also thought by salinity specialists that higher rainfall has a flushing or dilution effect. So while recharge may be higher in these areas, and groundwater systems perhaps more expansive, salt concentrations in the top soil is less obvious and water logging in years of excessive recharge becomes one of the main problems for areas with high watertables. This is common in the Warrenbayne area where high watertables can be a two edged sword. They can lead to water logging in very wet years but they can also extend the pasture growing season in drier seasons– especially where deep rooted perennial pasture has been established that can exploit water held in the deeper soil profile.

Phalaris in Warrenbayne at 250 m elevation after the 2018-2019 drought years. This site is managed with rotation grazing using guidelines developed for the MLA in an area with seasonally high watertables. Cattle were moved off this site just before this photograph was taken. Here there is seasonal water logging and groundwater discharge in very wet years but no salt accumulation. In dry years the watertable falls considerably. The bores in areas like this show large fluctuations in water levels showing water moves to lower areas in the landscape.

Elevation and slope

High watertables are found throughout the Warrenbayne and Boho areas at a range of elevations. Most current discharge sites are found between 250 m and 190 m elevation. Salinity is far worse at the lower end of this elevation range and is relatively common between 220 m and 190 m. For the higher areas this may be associated with higher rainfall and the flushing or dilution effect discussed above. But it may also be because these higher areas drain out into lower areas and sometimes directly into water ways and creeks and the watertables here contribute to the pressure that forces water to the surface in lower discharge areas. Characteristically at the higher elevations groundwater levels fluctuate seasonally and discharge may only occur in years of excessive recharge (see the hydrograph shown earlier). The late winter early spring of the very wet year of 2016 (1,154 mm was recorded at Glenisla in Warrenbayne) is a case when these areas were badly water logged. In contrast those areas where salinity occurs have consistently high watertable levels.

Watertable height

The height that the watertable needs to be before problems occur at the soil surface is open to conjecture. For example Aust Roads guidelines suggest at 3.0 m below ground surface watertables will have an effect on the soil at the surface for road construction and design purposes. However, conventionally for agricultural it is thought that 2.0 m below the ground surface will result in salt accumulation in the top soil if conditions are right. As the watertable approaches the surface, water is drawn up from the watertable by capillary action towards the surface bringing with it salts that were once stored in the deeper soil profile. Then in the right conditions evaporation removes water, leaving the salt behind and then pasture begins to suffer and the soil begins to degrade.

The situation in 2020

The Visualizing Victorias Groundwater database

The Visualizing Victorias Groundwater database is the main source of information on groundwater levels and changes in the water levels for Victoria. In this database there are more than 80 groundwater monitoring sites for the Warrenbayne and Boho areas. The last measurements entered in the database are for 2016 or 2017, although a few bores are still being monitored.

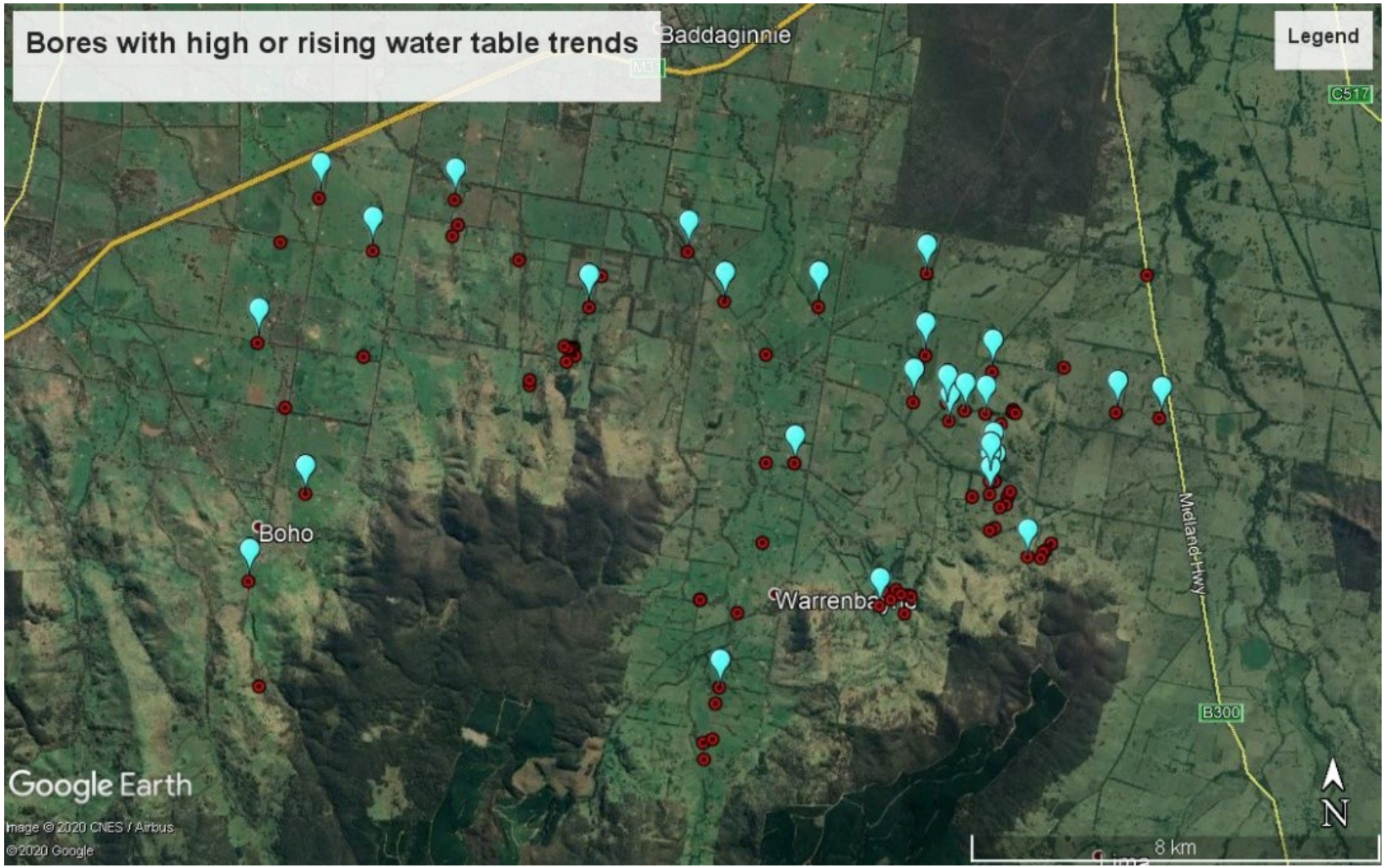
The locations of many of these bores are shown at the start of the previous section. Some of the bores are also listed in Appendix One with the year they were installed, depth to the bottom of the bore, elevation of the ground surface, the last groundwater height measurement that was entered, the trend in the watertable and the approximate location. Several of these bores haven't been monitored since 2012 or only have one measurement and so don't show the most recent trend in the watertable. For this report only those bores with measurements up to 2016 or 2017 are discussed unless there are clear trends in the watertable in the earlier records, or where single measurements or shorter record history may indicate a high watertable may exist.

There are several other bores in the National Soil Conservation Program (NSCP) site and 'break of slope' research sites around the Dobsons Rd hills east of Dobson's Rd and the Baddaginnie-Swanpool Rd in Warrenbayne. The trends in these bores will also be discussed in this section.

Because the bore network is located over 2 or 3 different land types and there are different trends across the area in the changes to groundwater levels, the bores will be discussed in the following order:

- Bores of the lower slopes:
    - The main Warrenbayne Valley along the Warrenbayne Creek from the top of the valley to just south of the Baddaginnie-Swanpool Rd and along Robinson's Creek.
    - Also in Warrenbayne: From south of the Baddaginnie-Swanpool Rd to the north including the Dobsons Rd hills surrounds to the Reef Hills and Midland Highway; and either side of Dobson's Rd at Broom Hills.
    - Warrenbayne West lower slopes below 1991 discharge zones.
    - The Boho Valley from the top of the valley to the Hume Freeway.
- Bores of the higher slopes:
    - The discharge and recharge areas of the NSCP research site in Warrenbayne.
    - Bores in the forestry sites in Warrenbayne and upper slopes of Warrenbayne West.

As indicated above these areas show differing trends- however there are some commonalities. There are several bores distributed fairly evenly across the Warrenbayne and Boho areas with either water levels within 3.0 m of the ground surface or with a consistent rising trend. The locations of these bores are shown in the image on the next page with a blue tag. Many of these bores are well away from current discharge and high recharge areas and indicate that there is potential for an expansion of salinity in Warrenbayne, Warrenbayne West and Boho.

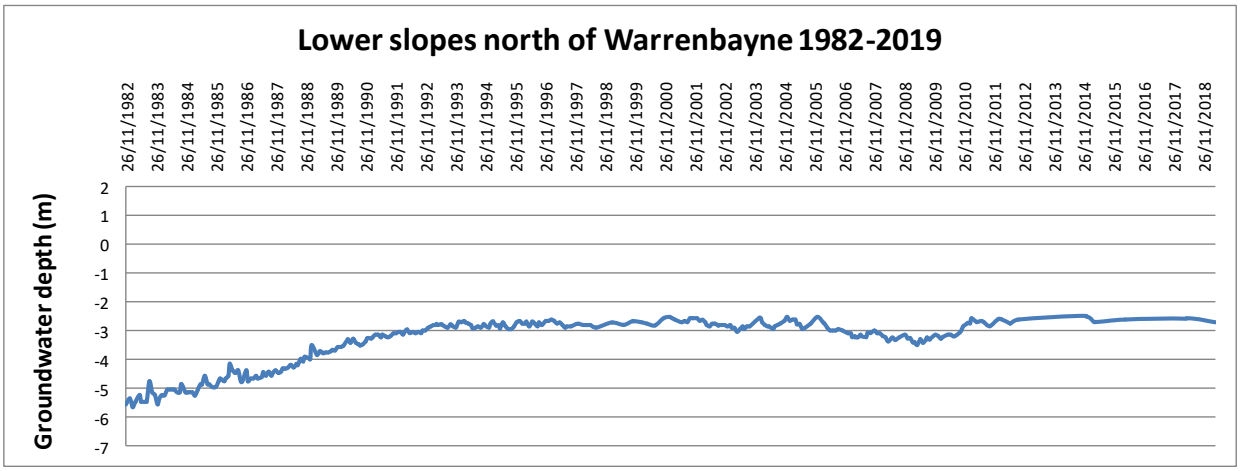


Watertable monitoring bores in the Warrenbayne and Boho areas. Those with a blue tag have hydrographs from the Victorian Visualizing Groundwater database that show water levels higher than 3.0 m below the ground surface or with a trend of rising groundwater.

Bores of the lower slopes

Bore 118847: Before these specific areas are discussed it is an appropriate time to see what has happened to the bore on Dobson's Rd (118847). The hydrograph of this bore from 1982 to 1991 is shown in the introduction and the updated hydrograph to the end of 2018 is shown below.

In this bore after 1991 the groundwater level continued to rise until 1993 before levelling out for a period of about 12 years and then falling until 2008 before rising again over the next 10 years. The net rise in water level between 1991 and 2018 was about 0.5 m which indicates that salinity has potential to worsen in the area near this bore.



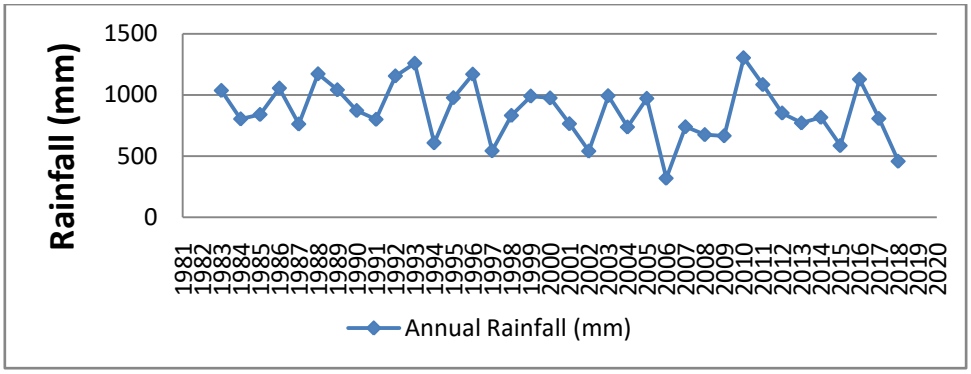
Hydrograph of the bore on Dobson's Rd – Bore 118847. This bore is located just under 1.0 km north from the Baddaginnie-Swanpool Rd and Dobson's Rd crossroad and about 0.5 km from the nearest high recharge areas to the east.

The fluctuation in water level closely follows the rainfall pattern over this 36 year period. Below is a plot of annual rainfall for Warrenbayne from the Bureau of Meteorology (BOM) recorder at Coramandel. These records don't have rainfall for 5 months between 1982 and 2016 and no records at all for 2017 and 2018. For these months and years the BOM records from Swanpool have been substituted. Swanpool is the next closest BOM recorder to Warrenbayne and usually has slightly lower rainfall than Warrenbayne. While not quite ideal the data is still useful for comparison purposes.

Table 1 shows that the initial rise in the watertable was during a period when the average rainfall was 980 mm. During the decline between 1994 and 2008 the water level fell about 0.8 m when average rainfall was 788 mm and then rose back up a similar distance between 2009 and 2018 when the rainfall average was 846 mm.

Rainfall was insufficient to recharge the groundwater system and raise the watertable here between 1994 and 2008. There also appears to be less recharge in the period 2009-2018 than for 1983-1993, however, the amount of recharge was sufficient to again raise the watertable at this site.

It should also be noted that this site was planted with trees for the Dobson's Rd corridor project in the 1990's and it is possible that the watertable is now being accessed by these trees slowing the rate of rise.



Annual rainfall recorded for Warrenbayne 1982-2019

Table 1: Change in watertable level in the Dobson Rd bore and average annual rainfall for the periods 1983-1993, 1994-2008, 2009-2018

Period	Annual rainfall (mm)	Approximate change in watertable depth
1983-1993	**980**	**+2.5 m**
1994-2008	**788**	**-0.8 m**
2009-2018	**846**	**+0.8 m**

Warrenbayne lower slopes: The upper valley floor

There are 5 bores with a sufficient record on the Visualizing Victoria's Groundwater database to indicate the recent trend in groundwater levels in the main Warrenbayne Valley. These bores are listed in Table 2. All of the bores had a trend of falling groundwater: the average fall since the bores were installed was 1.02 m. None of the bores measured in 2015 or 2016 had a level high enough to be considered a discharge zone. However, 2 of the bores had water levels within 2.0 m of the ground surface for part of their record indicating they at one time were in a discharge zone.

Table 2: Bores in the Warrenbayne Valley floor.

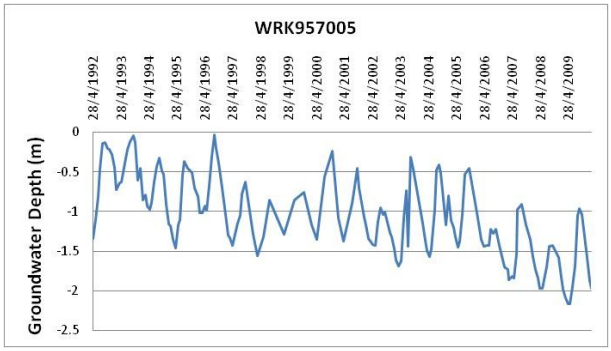
Warrenbayne area: Upper Valley Floor						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Comment
	(m)	(m)		(m)		
WRK957005	236.24	6.73	1994-2010	-1.96	-0.62	discharge site between 1994-2010
WRK957032	223.86		1991-2016	-3.75	-1.83	discharge site in 1991
118853	229.03	19.00	1982-2016	-8.03	-0.81	
WRK957004	221.29	8.69	1995-2016	-3.93	-0.31	
118859	213.14	8.00	1989-2015	-5.47	-1.52	
				average change	-1.02	

Bore **WRK957005** is one bore worthy of further comment despite its short monitoring history. This bore is located in the main Warrenbayne Valley about 1.5 km south of the Warrenbayne Hall. The water level fluctuated between 0.0 m and 2.1 m below ground surface between 1992 and 2010. The last recorded level in February 2010 was 1.96 m below ground level. The height of the watertable indicates that this was in a discharge area over the full recorded history. It is unknown what has happened in this bore since 2010. Perhaps further monitoring is warranted.

Nearby bores (some with only a single measured water level or short monitoring period) from the top of the Warrenbayne valley to the Baddaginnie-Swanpool Rd; and also along Robinson's Creek,

suggest a high watertable exists right across this area. It is likely that there was a significant area south of Bore WRK957005 that was a discharge zone during the past 25 years.

Groundwater levels and the last year of measurement in the Warrenbayne Valley were: **128898** (-0.50 m in 1997) (the minus sign indicates below ground level), **128897** (-2.61 m in 1997), **128899** (-3.56 m in 1997), **128900** (-2.19 in 1997), **WRK957032** (-3.75 m in 2016), **WRK957004** (-3.93 m 2016), **118860** (-2.32 m in 2016), **118858** (-2.96 m in 2016), **WRK958091** (-2.99 m in 2017), **124348** (-2.17 in 1995).



The water levels between 1992 and 2010 in the bore WRK957005 south of the Warrenbayne Hall.

On the western side of the Warrenbayne Valley there are only 2 bores that monitor water levels. These show that the watertable is deeper than in the centre of the valley and they also have a falling trend. This is consistent with our understanding of the groundwater system given the presence of a greater area of native forest and woodlands in the recharge areas to the west than in the east.

The Warrenbayne Valley from the high eastern (heavily cleared of native vegetation) slopes. The forested hills on the western side of the valley and the numerous tree plantations on the valley floor may be contributing to a downward trend in bore water levels.

The fall in water levels in the main Warrenbayne Valley are probably associated with the reduced rainfall and hence recharge since 1991 compared to pre 1991. However, it is also probable that tree planting in recent decades has had an impact. The photograph above shows how multiple tree plantations currently dot the valley floor. The photograph also shows the forested high slopes to the west which limit groundwater recharge so the water levels on the west side of the valley are deeper than elsewhere.

Then and now in the upper Warrenbayne Valley: These photographs show how tree planting is slowly changing the landscape in the upper part of the Warrenbayne Valley: Left 1995 showing what appears to be a water logged area at centre: Right 2020

Warrenbayne lower slopes: The Dobsons Rd hills and surrounds

The series of hills to the east of Dobson's Rd, north of the Baddaginnie-Swanpool Rd and west of the Midland Hwy are referred to here as 'the Dobsons Rd hills'. The bores located in the area surrounding these hills and across to Warrenbayne West and the Reef Hills are listed in Table 3.

Table 3: Bores in the lower slopes around the Dobsons Rd hills and to the Reef Hills and Warrenbayne West.

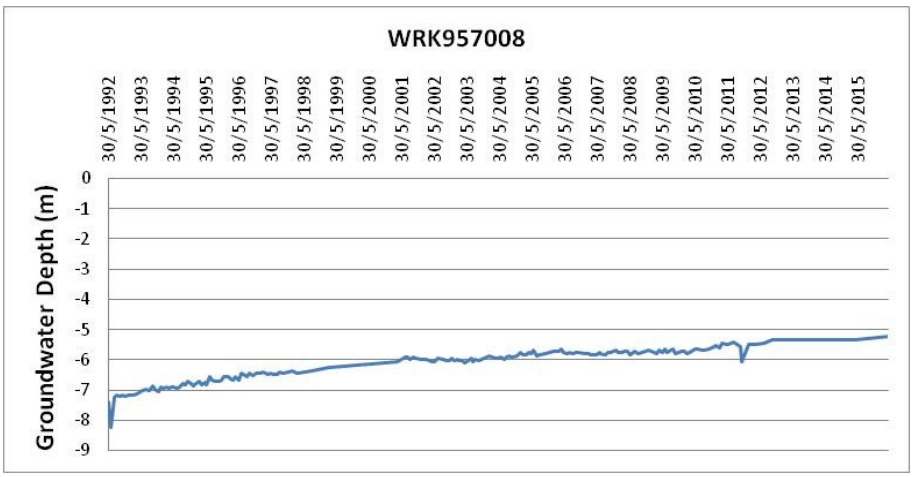
Warrenbayne area: The Dobsons Rd hills surrounds to Reef Hills and Midland Hwy						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Comment
	(m)	(m)		(m)		
118860	215.59	8.00	1989-2016	-2.32	0.04	
118858	208.48	10.00	1989-2016	-2.96	-0.01	
WRK957003	206.71	10.20	1992-2016	-4.41	-1.02	
118852	206.48	19.00	1982-2012	-2.88	1.39	
WRK957006	204.80	17.84	1992-2012	-9.36	0.05	
118847	203.11	11.00	1982-2016	-2.76	2.38	
118846	203.11	19.00	1982-2016	-2.61	2.96	
WRK957008	202.87	17.85	1992-2016	-5.22	2.17	consistent upward trend
WRK957009	201.34	16.81	1992-2012	-7.51	2.66	consistent upward trend
WRK957007	198.03	21.64	1992-2016	-17.69	3.25	consistent upward trend
WRK957010	199.64	10.45	1994-2016	-3.22	-1.15	possible discharge site
118862	195.67	10.00	1989-2016	-2.69	3.45	
118861	189.04	11.00	1989-2016	-1.94	0.11	discharge site
WRK956930	181.48	6.00	2004-2016	-4.45	-1.60	
				average change	1.05	

On the west side of the Dobsons Rd hills the bores are distributed from Dobson's Rd almost to the Reef Hills and to the Warrenbayne West Rd and on the east side to the Midland Highway. Unlike the main Warrenbayne Valley the bores here are generally high or they have a consistent slow rising trend or both. The average rise in the watertable was 1.05 m since the bores were installed. With the exception of bore **118861** (it is in a discharge area) they are located on the lower slopes below current discharge areas and the rising trend suggests potential for an expansion of the area affected by salinity.

On the west side of the Dobsons Rd hills this area is quite extensive. There are 5 bores with a consistent rising trend north of the Baddaginnie-Swanpool Rd and west of Dobson's Rd in an area extending almost to the Reef Hills. Based on the last recorded measurement the watertable ranged in depth from 2.61 m below ground surface on Dobson's Rd to 17.5 m below the ground surface

near the Reef Hills. An example of the slow upward trend is shown in the hydrograph for bore WRK957008.

The area either side of Dobson's Rd to the south of the Baddaginnie-Swanpool Rd could be included in this area because there are signs of salinity and high watertables on both sides of Dobson's Rd. However, there are no bores in this area.



The water levels in the bore WRK957008.

The bores around the Dobsons Rd hills in combination with those in the upper Warrenbayne valley show that the watertable in Warrenbayne extends continuously from the top of the Warrenbayne valley in the south about 10.0 km - almost to the Reef Hills. At the northern extreme while much of the water may have its origins in the high recharge areas in Warrenbayne the rising water table may also be associated with a far more expansive regional groundwater system further to the north. Further monitoring is needed to confirm this.

Warrenbayne West lower slopes

There are three bores of interest below current discharge areas in Warrenbayne West. They are listed in Table 4. They are located on both sides of the Warrenbayne West Rd between the Baddaginnie-Swanpool Rd and Boho Church Rd. They all show a slow more or less consistent upward trend in water levels similar to the area from the Dobsons Rd hills to the Reef Hills. The average rise in the watertable was 1.82 m since the bores were installed.

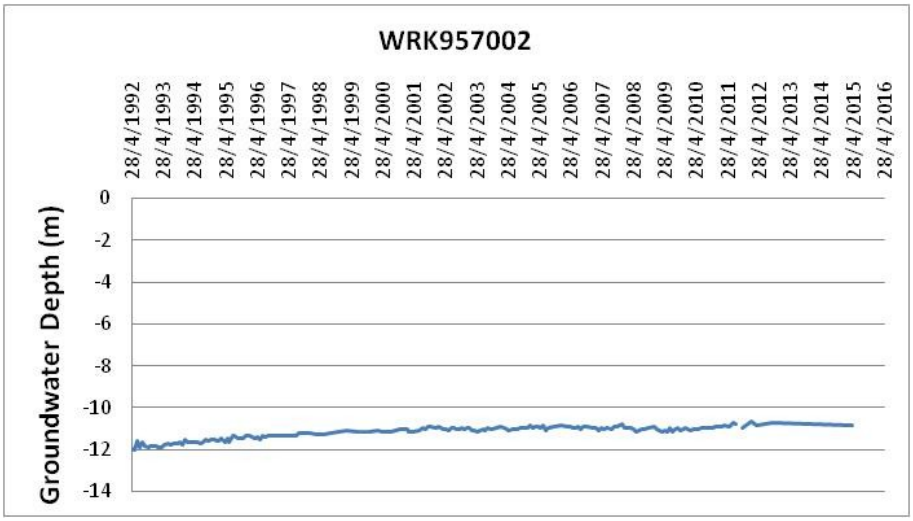
Table 4: Bores of the lower slopes either side of the Warrenbayne West Rd.

Warrenbayne West: Lower slopes						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Comment
	(m)	(m)		(m)		
WRK956928	214.09	19.00	2008-2016	-14.31	3.51	consistent upward trend
WRK957002	203.00	21.27	1995-2015	-10.85	1.17	consistent upward trend
WRK957013	194.83	16.90	1993-2017	-10.39	0.77	consistent upward trend
				average change	1.82	

The bores are within 2.0 km of the nearest high recharge area. In increasing distance from the nearest high recharge areas they are:

WRK956928. This bore is closest to the high recharge areas - the nearest being about 0.7 km to the southwest. The bore is located just over 1 km south of the Warrenbayne West Rd and about 2.0 km from the Baddaginnie-Swanpool Rd.

WRK957013. This bore is 0.5 km north of the Warrenbayne West Rd and 1.0 km East of the Boho Church Rd and about 0.8 km from the nearest high recharge area.



WRK957002. This bore is just north of the T-intersection of Warrenbayne West Rd and Baddaginnie-Swanpool Rd and 2.0 km from the nearest high recharge area. This site is 1.0 km north of a badly eroded 'salt scald' and may be evidence that the discharge area is expanding.

There was one other bore installed in 1992 in this area. That is **WRK957012** which is located 2.0 km north of the Warrenbayne West Rd and even further from the closest high recharge area. There are no water level records for this bore on the Visualizing Victorias Groundwater database probably because it didn't have water in it when it was first monitored. At the time of drilling it was obvious that the ground was exceptionally hard and the hole had to be abandoned without finding water. Even so the depth reached was 17.0 m which should have been deep enough to reach the watertable. This may indicate that the groundwater system from the recharge areas to the south doesn't extend out this far and the groundwater system is far less extensive here than further to the east between the Dobsons Rd hills and the Reef Hills.

The Boho valley floor

The Boho valley is not as well monitored as the lower slopes of the Warrenbayne valley, the Dobsons Rd hills area or Warrenbayne West. The bores in the research area south of School Rd in Boho were removed in the 1990's and the last measurement recorded in the Visualizing Victoria's Groundwater database was for 1994. There are 5 other bores that give recent trends in water levels but some of these have not been monitored since 2012. These along with one of the bores on School Rd are shown in Table 5.

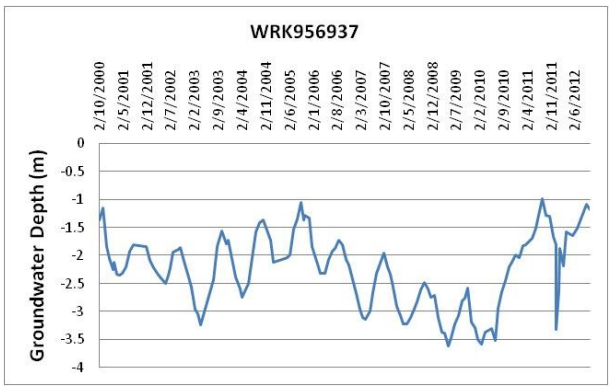
Table 5: The bores in the Boho valley floor

Boho Valley Floor						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Comment
	(m)	(m)		(m)		
WRK956937	229.21	6.00	2000-2012	-1.19	0.18	discharge site
118645	228.21		1982-1994	0.18	0.18	discharge site
WRK957016	201.17	12.45	1992-2016	-4.27	-0.89	
WRK957015	194.58	9.49	1993-2012	-2.08	0.42	discharge site
118674	193.93	17.00	1988-2016	-4.60	0.72	consistent upward trend
WRK957017	186.12	17.96	1999-2012	-15.08	2.11	consistent upward trend
				average change	0.45	

On the records available all but one of the bores has a rising trend with the average rise of 0.45 m since the bores were installed. Three of these are in discharge areas to the south and two in the north have the same consistent slow upward trend seen in the Dobson Rd/Reef Hills area and along the Warrenbayne West Rd.

The bores in table 5 are listed in order from south to north along the valley floor. They start 1.0 km south of the junction of the Boho Church Rd and the Boho Rd and finish 0.7 km from the Hume Freeway in the north. The watertable is probably continuous for a distance of at least 7.0 km; and over much of this area it is rising and there are (or have been) a number of discharge sites between 1982 and 2016. At the northern extreme it is unknown if the rising trend is associated with a regional groundwater system. As with the situation in Warrenbayne further investigations are needed to determine if this is the case. Some of these bores and others found in Boho on the Visualizing Victoria's Groundwater database are discussed below:

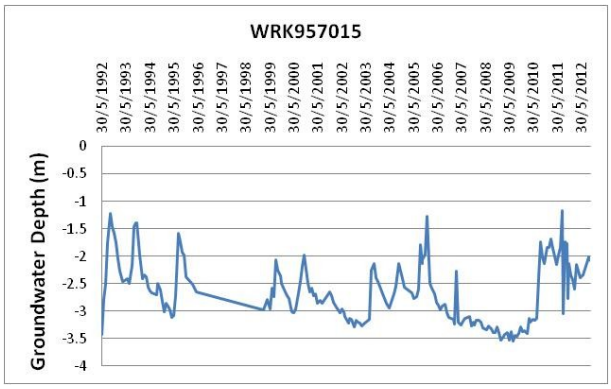
WRK956937: This bore is located 1 km south of the junction of Boho Church Rd and Boho Rd. The water level was fluctuating but relatively stable in height between 2000 and 2012. The last recorded level was in 2012 at just over 1.0 metre below ground level indicating that it was in a discharge area during this period.



WRK957016: Located near Creamery Rd, 1 km from Smiths Rd. The water level between 1992 and 2016 fluctuated and there are indications of a slight trend downwards although this trend changes rapidly and with a succession of wet years could easily have an upward trend. In 2016 the water level was 4.27 m below ground level.

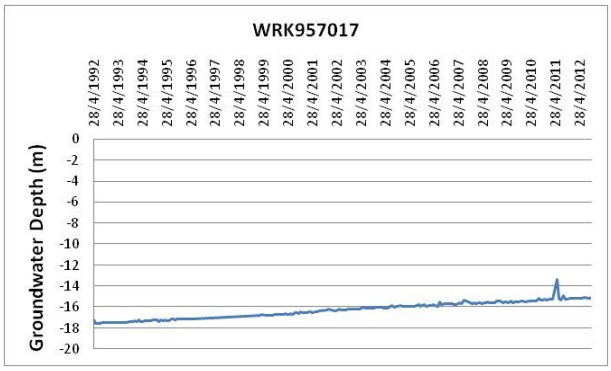
118670: This is another of the older bores found on the Visualizing Victoria's Groundwater database. It is located on Smith's Rd, 300m from Boho Church Rd. There is only one measurement. In 2005 the water level was 3.37 m below ground surface.

WRK957015: This bore is also on Smith's Rd, 2.5 km from the Boho Church Rd. The water level here has fluctuated with an overall upward trend. The last record is for 2012 when the water level was 2.08 m below ground level. The water level here suggests this bore is in an area that for much of the time between 1992 and 2012 was a discharge area.



118674: This is an older bore with water levels recorded between 1988 and 2016. It is located on Leo's Rd, 500 m from the Boho Church Rd. The water level rose 0.72 m between 1988 and 2016 and was 4.5 m below ground level in 2016.

WRK957017: This bore is located 750 m from the Hume Fwy and 1.7 km west of the Boho Church Rd. It has a slow and steady rising trend. The water level rose 2.11 m between 1992 and 2012. The last recorded measurement was 15.08 m below ground level.



The incomplete records and the high and rising watertable trends in Boho suggest it may be in the local farming community's interest to have further monitoring of the watertable here. The trends, initially at least, suggest a different situation in the upper Boho Valley compared to the upper Warrenbayne Valley.

Bores of the higher slopes

The NSCP research site

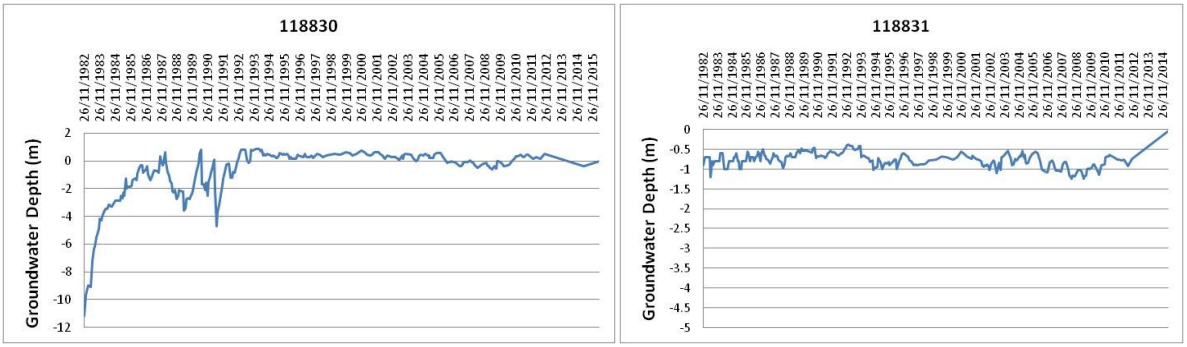
The bores of the NSCP (National Soil Conservation Program) research site are located either side of the Baddaginnie-Swanpool Rd to the east of Dobson's Rd in Warrenbayne. They are strategically located across the landscape from the high recharge areas either side of the Baddaginnie-Swanpool Rd, across the break of slope and into the discharge areas on either side of the road. Along with the research site on School Rd in Boho they were set up in 1982 to investigate the groundwater system. In the case of the NSCP site in Warrenbayne the project also included fairly extensive treatment of

high recharge areas with the planting of deep rooted trees, shrubs and grasses. The bores on the NSCP site have been monitored continuously since 1982 with the last measurement entered into the Visualizing Victoria's Groundwater database in 2016 or 2017.

One of the several plantations of native trees and shrubs established in the 1980's by Colin and Helen Davies on high recharge areas of the NSCP site in Warrenbayne.

Bores in the discharge zone of the NSCP site

All of the bore water levels in the discharge zone have remained at or above the surface or just below the surface with little change in water levels from soon after they were installed until 2016. The two hydrographs below are typical of the trends. Despite the treatment of the recharge areas there has been no obvious change to the groundwater levels.



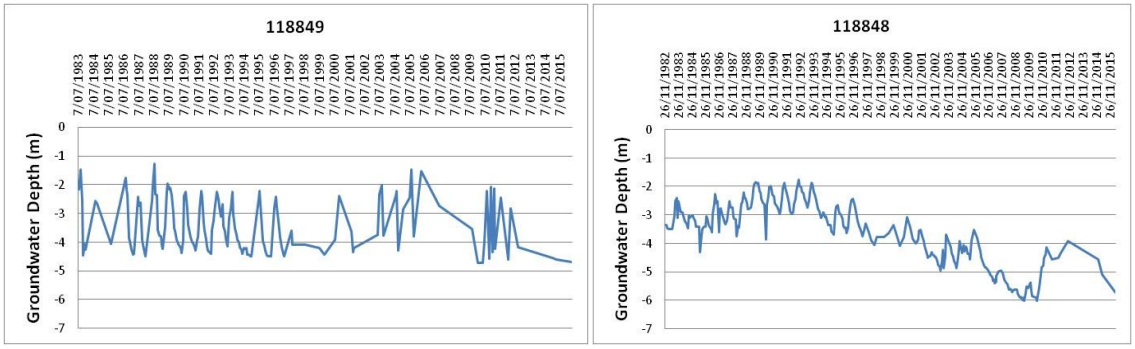
Hydrographs of two bores in the discharge area of the NSCP site in Warrenbayne located at 224 m elevation.

Bores in the recharge areas of the NSCP site

There is however, a change in water levels in the recharge areas higher in the landscape. The two hydrographs shown below are for bores located at 250 m elevation i.e. 30 m higher than those in the discharge zone (above).

The bore on the left is a shallow bore that shows the effect on a shallow watertable when recharge occurs. There is a marked absence of recharge in a few years after 1996 which is consistent with lower rainfall and the trends in the bore on Dobson's Rd discussed earlier. However, there are a number of later years where the amount of recharge returned to earlier levels – again consistent with the trends in the Dobson's Rd bore.

The bore on the right is a deeper bore and shows what is happening to the deeper more regional groundwater system in the higher slopes. The water levels have consistently fallen in a similar manner to this in all of the deeper bores above the break of slope. What is impossible to tell from these hydrographs is how much of the fall in water levels is due to lower rainfall and hence lower recharge and how much due to the treatment of high recharge areas. The reason for this is there are no bores for comparison in areas where there has been no tree planting. However, it is probable that there is an influence from both.



Hydrographs of two bores in the recharge area of the NSCP site at 250 m elevation.

Bores of the break of slope forestry sites

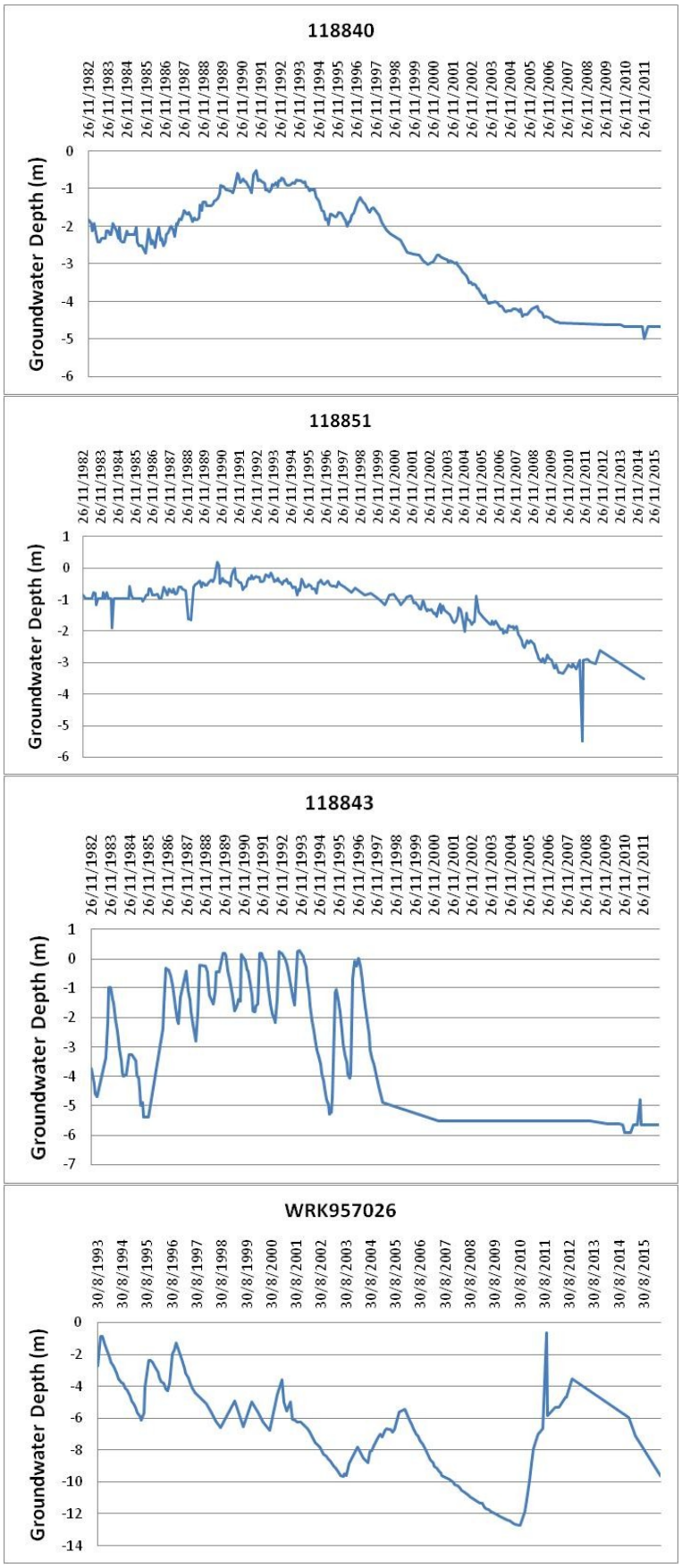
There are a number of break of slope forestry sites where watertables have been monitored in Warrenbayne and Warrenbayne West. They all show a similar trend in water levels in the bores close to forestry sites. The most significant of these are discussed below:

The Dobsons Rd hills forestry sites

On the northwest side of the Dobsons Rd hills the trends in the bores are different to the NSCP site (the south side). Unlike the NSCP site trees were planted along the break of slope just above an extensive discharge area between 1995 and 2004. There are 7 bores located either in the plantations, just above or just below the plantations. All of the bores had water levels at or near the surface in the early 1990's and by 2016 the water level had fallen by up to 9.66 m.

For the purpose of comparing trends in water levels near the break of slope plantations to sites where there are no break of slope plantations, all of the bores on the NSCP site and the Dobsons Rd hills are listed in Table 6 in three categories: (i) Bores associated with the break of slope plantations: (ii) Bores at a similar elevation where there are no break of slope plantations: and (iii) Bores of the higher slopes.

Table 6 gives the average change in water level for each of the three categories since 1991 or when the bore was installed (if installed after 1991). All have a falling trend. The average falls were 5.44 m near the break of slope plantations, 0.26 m near the break of slope where there are no plantations and 2.25 m fall in the higher slopes (where there are plantations in high recharge areas).



Hydrographs for some of the bores associated with break of slope plantations on the Dobsons Rd hills.

Table 6: Bores of the NSCP site and around the Dobsons Rd hills are listed in three groups: (i) Bores associated with the break of slope plantations: (ii) Bores from the break of slope and discharge areas where there are no break of slope plantations: (iii) Bores of the higher slopes and high recharge areas.

Bores in or next to BOS plantations in discharge zones					
Bore #	Elevation (m)	Bore Depth (m)	Monitored	Last level (m)	Change (m)
118850	217.21	7.00	1982-2016	-4.20	-4.35
118851	217.24	6.00	1982-2016	-3.00	-3.05
118840	224.15	5.00	1982-2012	-4.60	-3.85
118841	224.32	3.00	1982-2012	-2.95	-1.94
WRK957026	229.92	17.45	1993-2016	-9.66	-6.99
WRK957027	226.23	31.35	1993-2016	-7.82	-7.82
WRK957028	226.23	50.20	1993-2016	-7.77	-7.77
118842	233.92	19.00	1982-2016	-12.70	-11.34
118843	233.80	6.00	1982-2016	-5.60	-5.28
WRK957025	237.35	7.40	1993-2016	-6.56	-1.96
			Average	**-6.49**	**-5.44**

Bores in untreated discharge zones					
Bore #	Elevation (m)	Bore Depth (m)	Monitored	Last level (m)	Change (m)
118846	203.11	19.00	1982-2016	-2.61	0.67
118847	203.11	11.00	1982-2016	-2.76	0.58
118844	217.14	16.00	1982-2016	1.02	-0.15
118845	216.96	9.00	1982-2016	-0.17	-1.52
118835	226.27	14.00	1982-2016	-1.09	-0.79
118836	226.19	8.00	1982-2016	-1.32	-1.14
118837	226.27	3.00	1982-2012	-1.06	-0.89
116692	224.20	100.00	1984-2016	-1.71	-0.57
118829	224.43	25.00	1982-1993	1.27	0.30
118830	224.00	15.00	1982-2016	-0.56	0.56
118839	222.30	19.00	1982-2012	-0.83	-0.08
118831	229.00	19.00	1982-2016	-0.21	0.44
118832	228.96	7.00	1982-2016	-1.48	-0.74
			Average	**-0.89**	**-0.26**

Bores in high slopes in or near high recharge areas					
Bore #	Elevation (m)	Bore Depth (m)	Monitored	Last level (m)	Change (m)
118838	243.40	8.00	1982-2012	-7.24	-1.82
116694	238.84	30.00	1982-2016	-5.28	-0.37
116693	242.21	30.00	1984-2016	-8.56	-2.38
118833	239.30	19.00	1982-2016	-3.65	-3.06
118834	239.36	14.00	1982-2016	-4.09	-3.02
118848	249.96	18.00	1982-2016	-5.71	-3.12
118849	249.53	5.00	1982-2016	-4.67	-0.67
116691	248.58	30.00	1982-2016	-8.55	-3.57
			Average	**-5.97**	**-2.25**

While the large differences in water levels may be co-incidental, or something to do with differences in the groundwater system on either side of the Dobsons Rd hills, large falls in watertables like this are commonly found in forestry. The Goulburn Broken CMA has in the past even had concerns about water yield from forested catchments for this reason. It is well known that plantations that are established to maximise the growth of wood use more water than falls as rainfall if it is accessible to the root systems. Sap flow measurements conducted in Warrenbayne in the mid 1990's confirmed this was the case with southern blue gum plantations established on the break of slope in 1992. These plantations were thought by tree water use specialists to have dewatered the root zone causing watertable to fall dramatically before the trees began to die in the subsequent droughts of the mid 1990's.

Inside one of the spotted gum break of slope plantations on the Dobsons Rd hills – planted by Jim Dalton in 2004. Along the base of the Dobsons Rd hills the watertable in this vicinity fell an average of 5.44 m between 1991 and 2016.

One of the break of slope plantations at the base of the Dobsons Rd hills showing the scars of an old saline discharge area in the fore ground. This site is no longer a discharge area.

The Warrenbayne West forestry sites

Substantial falls in watertables in other forestry sites are also recorded on the Visualizing Victorias Groundwater database in the Warrenbayne West area. Table 7 gives the trends for 2 forestry sites located at: (i) Rotherlea south of the Warrenbayne West Rd: And (ii) Old Sunvue on Roach's Rd.

There are 6 bores on Rotherlea and one on Old Sunvue. The average fall in water levels was 3.84 m since the bores were installed. Maps of these two sites are shown below - they show where the bores are located and location of the break of slope plantations and recharge treatment.

Table 7: Bores at the forestry sites in Warrenbayne West.

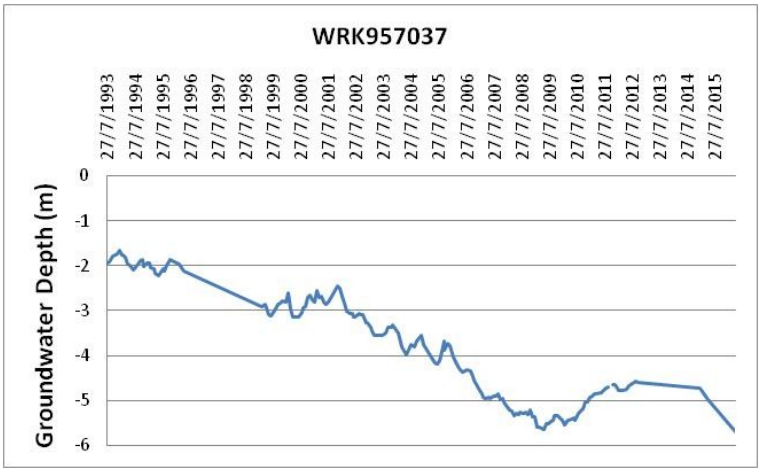
Warrenbayne West: Bores associated with Break of Slope Plantations						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Comment
	(m)	(m)		(m)		
116695	238.36	40.00	1987-2016	-10.55	-5.50	plantation
116696	232.72	50.00	1987-2016	-10.01	-2.07	tree plantation
WRK957035	225.08	21.60	1994-2016	-8.77	-3.43	tree plantation
WRK957036	224.55	49.19	2000-2016	-7.21	-3.53	20 m east tree plantation
WRK957037	222.95	24.59	1994-2016	-5.71	-3.76	once a discharge site near plantation
WRK957038	221.94	19.97	1994-2014	-5.92	-2.69	90 m east of plantation
118673	208.06	9.00	1988-2017	-7.98	-5.90	below tree plantations Sunvue
				average change	-3.84	

Rotherlea

The site on Rotherlea has multiple break of slope plantations located along the east and western slopes of the valley as well as treatment of recharge areas with plantings of Tagastaste and eucalypts.

Rotherlea: View to the east from the western high recharge area showing multiple break of slope plantations on the eastern and western side of the valley.

Rotherlea: Bore and plantation locations.

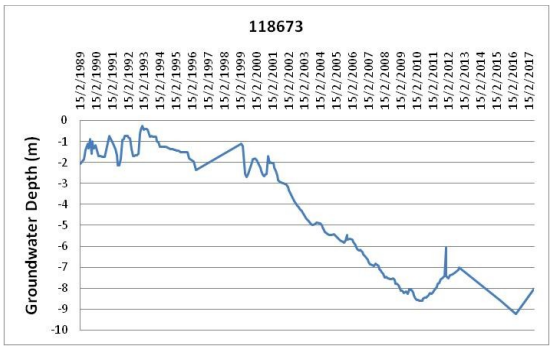


Bores were installed to monitor watertable trends through one of the plantations out into the valley floor starting at an elevation of 238 m just above the break of slope, to 222 m elevation 90 m away from the nearest plantation. In 1993 and 1994 bore WRK957037 had a water level less than 2.0 m below the ground surface indicating that groundwater was discharging at this site; by 2016 the water level had fallen to 5. 71 m below the ground surface. The hydrograph is shown above. The other 5 bores have a very similar trend.

One of the differences between Rotherlea and the Dobsons Rd hills is that the watertable has fallen up to 90m away from the plantation indicating that the plantations are having an off-site effect while it appears to be a more localized trend on the Dobsons Rd hills.

Sunvue

The site at Sunvue differs again to both the Dobsons Rd hills and Rotherlea. Here there is an old discharge site that was first treated by planting with salt tolerant grey sheoak in the 1980's. Later tree plantations of southern blue gum and river sheoak were added on the break of slope or just below the break of slope. The watertable fell around 6.0 m between 1993 and 2017. Once again like on Rotherlea there appears to be an off-site effect.



Sunvue: Once a saline discharge area on Roach's Rd, Warrenbayne West, the water level has fallen 5.90 m since 1988 (Bore 118673). The site has multiple tree plantations with southern blue gum and river sheoak on the higher slopes (the break of slope) and grey sheoak on what was at one time a discharge area.

Sunvue: The location of Bore 1188673 (to the right near Roach's Rd) relative to the high recharge area (to the left), break of slope plantations and plantings in the discharge area.

The tree planting at Sunvue was a project of Reg and Joan Roach and this is not the only site where they had an impact on the watertable. Further west on the Warrenbayne West Rd there is another site on Rockbank where the watertable has also fallen. This time it is a saline discharge site that was planted with grey sheoak and a couple of species of box trees in the 1980's. The watertable (**Bore 118671**) has fallen 1.39 m and it is no longer a discharge site.

Treatment strategies

Treatment of recharge areas

Given that removal of deep rooted native vegetation in high recharge areas is the major cause for increased recharge, rising groundwater levels and ultimately salinity and soil degradation, it follows that returning deep rooted perennial plant species to these areas is the obvious solution. During the 1980's and into the 1990's this was the focus on salinity treatment in Warrenbayne and Boho.

Bore water levels suggest that this strategy has had little if any impact on local salinity and a rising regional watertable on the lower slopes. No doubt this is because insufficient treatment has been put in place. Never the less below is a summary of what has worked in terms of survival.

High density tree plantations on rocky 'high recharge' areas

At the outset when the salinity program started in Warrenbayne and Boho in the 1980's replanting of the worst rocky high recharge areas was the major focus with what was termed 'high density tree plantations'. There are numerous examples of these plantations in the Warrenbayne area on the NSCP site, the Dobsons Rd hills, the Harrison's Rd catchment, Warrenbayne West and Boho. These plantations used a range of species and some have survived well. Below are photographs of those species that have survived to the present day in good numbers and in good vigour.

High density tree plantation on a high recharge area in the Harrison's Rd catchment – planted by John Harrison in the late 1980's. The trees shown are yellow box that have survived well for more than 30 years. Yellow box is also well represented in many other high recharge plantations throughout the Warrenbayne and Boho areas.

The Benalla Tree Group Project on a high recharge area on the Dobsons Rd hills planted by John Davies in the early 1980's: Silky oak, river sheoak, sugar gum and spotted gum have all survived well.

Red iron bark on the boundary between Rotherlea and The Elms in Warrenbayne West - planted in the 1980's by Pam Robinson and Angus Howell. Red iron bark is found growing well in several places but there have been a few recent drought deaths on the NSCP site. Thinning (i.e. the removal of competing trees) will help them survive.

Low density tree plantations on high recharge areas

Another strategy that was attempted was the planting of 'low density tree plantations' in the late 1980's. This change in strategy acknowledged the difficulty faced by most landowners in establishing high density tree plantations. Low density tree plantations were planted at the wider spacing of 20 trees per hectare in individual tree guards. There are several examples of these in Warrenbayne and Boho. Most have not survived well at the original stocking rate and research in 1992 cast doubt on their effectiveness to limit recharge - and the concept was abandoned soon after.

Low density tree plantation established on Fairview in Warrenbayne. This is a rare example of the concept because most sites have had several tree deaths.

Fodder as a treatment for high recharge areas.

With commercial viability in mind for grazing sheep and cattle in the high recharge areas while treating salinity, Tagastaste and phalaris were established in a number of areas in the 1980's and 1990's. There are many examples of good survival for both options.

High recharge treatment with Tagasaste: Here is an example from Warrenbayne West.

Occasionally phalaris was hand sewn on high recharge areas. This example is from the NSCP site in Warrenbayne. Phalaris is still growing well after more than 35 years in a number of locations.

Deep rooted pasture in moderate recharge areas

The use of deep rooted pasture can be extended to all parts of the landscape where recharge occurs. While they won't solve the problems associated with the high rocky slopes every bit helps. In moderate or even low recharge areas phalaris can be established relatively easily if Aluminium toxicity in highly acidic soils is addressed. There are several stands of phalaris throughout the Warrenbayne and Boho areas and many have been continuously grazed since the 1950's or 1960's - and establishing phalaris pasture is still continuing today. Research has shown that rotation grazing of these pastures using the guidelines for pasture height limits and leaf development now promoted by the MLA will maximize pasture production and in these circumstances will maximise groundwater use. The aim of retaining ground cover and a minimum pasture height target with this strategy has the added benefit of reducing soil erosion. Deep rooted native grasses can also be used in a similar way, although modern phalaris cultivars have been selected to maximize pasture production.

Phalaris established at 250 m elevation on a site that is for part of the year a moderate recharge area and in wet years it can become a seasonal discharge site as the watertable temporarily rises toward the soil surface. This stand was established in the 1960's and is now in a rotation grazing situation where cattle can be taken off if the soils are saturated in the late winter.

Managed regrowth on high recharge areas

Managed regrowth of native woodlands is an option that has found its way into the list of treatment strategies. This is the regeneration of native woodland species like yellow box, other box species, red gum, red stringy bark and native shrubs in areas with remnant vegetation. This strategy has worked best where sheep have been removed and replaced with cattle and especially with rotation grazing – and it can work even if areas aren't fenced to exclude stock. An example is on Glenisla in the Harrison's Rd catchment.

The Grassy Woodlands site (Paul and Betty Schultz's hill) also in the Harrison Rd catchment throws up another option in this category of treatment. This is closer to 'land retirement' where stock are removed altogether or at best grazed only occasionally. This site has good regeneration of woodland grasses, shrubs and trees across a large area of the rocky high recharge area in Warrenbayne. This is the only example of broad scale treatment of the high recharge areas found during the survey of treatment strategies for this report.

Rotation grazing where there is a minimum pasture height target and the example of grassy woodland regeneration described above have another benefit. At the end of the drought in 2018 both of these farms had retained good ground cover when heavy rains fell at the end of summer and into autumn in 2019 – this prevented the widespread soil erosion seen across the higher slopes of much of Warrenbayne and Boho where annual pasture dominates.

Red stringy bark and box regeneration on Glenisla, Harrison's Rd catchment.

Regeneration of yellow box and other box species on the grassy woodlands site in the Harrison's Rd catchment.

Deep rooted grasses in the grassy woodlands project on the right and conventionally grazed shallow rooted annual pastures on the left.

Forestry in recharge areas

Forestry in high recharge areas has limitations because of access and the rugged nature of country. However, there are examples of forestry in the more accessible areas – most of these sites are moderate recharge areas.

Spotted gum on Broom Hills in a moderate recharge area – planted in 1993 by Bill and Debbie Hill.

Radiata pine on a high recharge area in Warrenbayne. The trees were planted and managed by Emmie de Fazio with thinning and pruning. This photograph was taken in 1995 and the plantation has since been harvested and logs sold locally. Trees are now regrowing on the site and there is an intention to prune and thin them for a future harvest.

High growth and form rated clones of Radiata pine on a moderate/low recharge site on Broom Hills managed with thinning and pruning – established by Bill and Debbie Hill in 1993.

Top: Wide spaced pruned Radiata pine seedlings planted in 1992 on Glenisla, Harrison's Rd catchment on a moderate recharge site. Cattle are allowed to graze here using MLA rotation grazing guidelines. Bottom: Sydney blue gum and flooded gum on the same site.

Break of slope plantations

The concept of plantations on the break of slope came about in the late 1980's when it became obvious that planting in high recharge areas had limitations. The idea was to place plantations capable of using large quantities of groundwater on the break of slope where the watertable was close to the ground surface and accessible to trees throughout the year.

Many of the early plantations were southern blue gum because it was known that the species was capable of using large quantities of groundwater if it were accessible to the trees. It was also recommended by the Centre for Forest Tree Technology and CSIRO Forestry and Forest products because of its acceptance by existing processing industries. However, as time progressed the number of species grew and the sites planted became more varied as landowners themselves experimented with different options.

Southern blue gum

Southern blue gum has only been a partial success. The species can access and use groundwater and it is associated with the largest falls in the watertable found in several sites in Warrenbayne and Warrenbayne West. However, in most cases it hasn't grown well and there have been numerous drought deaths in some locations. Even on the better sites drought deaths have occurred and where it has survived well the unmanaged stands don't inspire many people because of their appearance. However, there is a site selection, tree management and genetic aspect to the species to consider.

Southern blue gum genetics trial on Glenisla in the Harrison's Rd catchment at 255 m elevation – planted in 1992 with 54 genetically different types of southern blue gum and managed with thinning and pruning. This plantation is located in an area where the watertable fell 6.0 m between 1995 and 2012.

The best surviving break of slope plantation is the one on Glenisla in the Harrison's Rd catchment. Most of the early break of slope plantations used the Jeeralang Provenance of southern blue gum which has its origins in the high rainfall and cool climate of South Gippsland. The plantation on Glenisla is different because it used 54 different families (a family are trees selected from one parent tree) of southern blue gum selected from the geographic range of the species and includes all three

sub-species *Eucalyptus globulus* subsp*. globulus, E. globulus* subsp *pseudoglobulus* and *E. globulus* subsp *bicostata* (the latter subspecies is found growing in the Strathbogie State Forest a few km to the south). Many of the original families are no longer represented in the plantation and only those trees with the best growth and drought tolerance remain – a process of natural selection. The other difference with this plantation compared to all others is that it was thinned and pruned which has improved the trees appearance, drought tolerance and its ultimate utilization potential.

Selected trees from the same genetic sources as the break of slope plantation on Glenisla that shows the species potential on the better sites in Warrenbayne – planted in 1992. These plantations are a potential source of seed from trees known to be suited to the climate in Warrenbayne. Even with selection the species appears to be best suited to sites with greater than 750 mm rainfall, deep soils and with a watertable accessible to the trees.

Radiata pine

There are several plantations of Radiata pine in Warrenbayne and Warrenbayne West under a variety of management including conventionally thinned un-pruned stands and wider spaced pruned stands that have been spaced to a range of stocking rates.

The stand shown below is one established on Glenisla in 1994. It was thinned to 320 trees per hectare on the advice of tree water use specialists and pruned to 6.6 m by 2003. This plantation is located on one of the better sites for Radiata pine in the Warrenbayne and Boho areas, so the stocking rate here is probably too high for most other locations.

Radiata pine is probably best suited to the same types of sites as southern blue gum. i.e. greater than 750 mm rainfall, deep soils and access to the watertable.

Radiata pine break of slope plantation established on Glenisla in the Harrison's Rd catchment on a site with seasonally high watertables – planted in 1992 with high growth and form rated clones.

The spacing chosen for the plantation on Glenisla aimed to maximise water use.

Spotted gum

Spotted gum has been planted in break of slope plantations on the Dobsons Rd hills and with Southern Blue Gum is known to lower the watertable.

There have been some problems with frosts which killed trees at -6.0 degrees in 1991 in Warrenbayne. However, frost susceptibility may vary between Provenances. While the species grows along the east coast of Australia the most southerly range is in East Gippsland and this Provenance could be more tolerant of frosts than those from further north. The Provenance planted around the Dobsons Rd hills had no issues with frost and it is thought to be Victorian. The issue of frost can also be overcome by planting high in the landscape above where the worst frosts occur.

Thinned spotted gum break of slope plantation on Rotherlea in Warrenbayne West.

Most of the plantations that are found in the area haven't been thinned or if they have the thinning was late. For example the trees on the Dobsons Rd hills which are now 16 years old are still at around 1000 trees per hectare. The survival rate is exceptionally high for this stocking rate which shows just how tolerant of competition and drought the species is and indicate that they can be grown throughout the Warrenbayne Boho area. On Rotherlea the trees appear to have been recently thinned and they are relatively small for their age. On the best sites and given plenty of space to grow their growth rates are among the fastest of the eucalypts that are found growing in the area.

Flooded gum

Flooded gum is a northern species that has shown good adaptability to the Warrenbayne and Warrenbayne West areas. It is drought tolerant and is relatively tolerant of frosts although care should be taken with young trees.

Flooded gum on Glenisla on what was once a discharge zone at the break of slope.

On Glenisla there is one plantation that was established in 1994 with CSIRO clones selected to tolerate water logging and salinity in the irrigation areas of Shepparton and the Riverina. They were planted on a very wet area with a high watertable. The site was so wet at planting mounds had to be built up to keep the trees out of water. The survival rate at 28 years after thinning of unwanted trees is exceptional with no deaths and the trees have required very little management.

Flooded gum in Warrenbayne West on the lower slopes; while this is not a break of slope site it shows how the species can grow in the area on rainfall alone – the species can be grown on sites with greater than 600 mm rainfall.

Sydney blue gum

Sydney blue gum is another species that is frost sensitive and it has been difficult to establish on colder sites in the area. However, on Rotherlea it has survived well in break of slope plantations without thinning which shows just how drought tolerant it is. The photographs below shows the trees on Rotherlea and some that were thinned and pruned on Glenisla.

Unthinned and unpruned Sydney blue gum on the break of slope on Rotherlea and 30 year old thinned and pruned trees on Glenisla in Warrenbayne. Another closely related species southern mahogany gum (*E. botryoides*) is also with the trees at Glenisla. In the plantations found in Warrenbayne and Warrenbayne West southern mahogany gum rarely performed well.

River Sheoak

River sheoak is another species that is well represented in Warrenbayne and Warrenbayne West. It is an excellent survivor and grows well in most parts of the landscape with the exception of saline discharge sites where the grey sheoak (*Cassuarina glauca)* is a better proposition. There is an example of river sheoak on the break of slope on Glenisla and one on Rotherlea near the valley floor. The photograph below shows 26 year old trees on Glenisla that have been pruned and lightly thinned. These were planted on what was once a seasonal discharge site.

River sheoak on the break of slope on Glenisla, Harrison's Rd catchment, Warrenbayne – planted in 1994 and managed with thinning and pruning unwanted branches.

Red gum

Red gum is also found on the break of slope on Glenisla in the Harrison's Rd catchment and there are other plantations of red gum on numerous sites in Warrenbayne, Warrenbayne West and Boho. In the case of Glenisla it was at first planted and when natural regrowth started on the same site the emphasis changed to encouraging and managing the regrowth rather than going to the expense of planting trees. Regrowth red gum has been managed on a couple of sites on Glenisla with the oldest dating back to the 1980's. The photographs below show a couple of stages of management and what the trees look like when finished.

Thinning small unwanted regeneration – the thinned trees are just starting to regrow and will be removed in due course.

A few years later with trees at about the final spacing.

Thinned red gum from 1984 regeneration. This is not a break of slope site (it is a moderate/low recharge area) but it shows what the trees look like if dense regeneration is managed. Apart from using groundwater it is unlikely that these trees will have any other use than supplying fire wood from fallen branches, shelter for livestock and pasture and a way of halting the decline of remnant trees. This site was temporarily fenced in 1983 to allow the regeneration but later experience shows that fencing is unnecessary.

Sugar gum and red iron bark

Sugar gum is not planted widely in the Warrenbayne and Boho areas and is not grown in any break of slope plantations that were inspected by the author. However, it is a species that should be considered. One shelter belt on the lower slopes is located on Rotherlea in Warrenbayne West and trees were also found in a couple of recharge areas showing it is a good survivor and very drought tolerant. Sugar gum also grows well in a range of environments right across the southern Murray Darling Basin. The only down side is frost sensitivity and the same cautions that apply to Sydney blue gum, flooded gum and spotted gum also apply to sugar gum.

The situation is almost identical for red Iron bark except it isn't frost sensitive. There are a few plantations on the slopes on Broom Hills in Warrenbayne and there are trees on the high recharge area between Rotherlea and The Elms in Warrenbayne West that were discussed earlier, but none are located on the break of slope.

Sugar gum on Rotherlea (left) and red iron bark on Broom Hills (centre). Both species are excellent for furniture timber and they are drought tolerant if managed to avoid too much competition between trees. On the right are the red iron bark on The Elms on a high recharge area showing the potential for stem straightness and what will happen if trees are given enough space to grow.

Treatment of saline discharge areas

The strategies that have been adopted for saline discharge areas in the Warrenbayne Boho areas are few. The main aim has been to slow down the loss of top soil. Tall wheat grass has been sown in a number of places and is a good survivor. Planting with salt tolerant trees has been another option with grey sheoak (*Cassuarina glauca*) a favourite that has also survived well.

Wood products.

With the development of break of slope plantations in the Warrenbayne and Boho areas there was a change in strategy for the management of watertables and salinity treatment with a focus on commercial forestry. This change came about because of the difficulties associated with treatment of the high recharge areas. It is fair to say that with a few exceptions this focus was lost over the years because of a range of factors: (i) Not the least being the successive droughts in the mid 1990's that damaged many of the southern blue gum plantations that were planted on the break of slope: (ii) And, southern blue gum requires some attention from tree growers and careful management is required if it is to survive well and have an acceptable appearance.

In this section, with the experience of the years that have passed since the 1990's and knowing which species grow successfully in Warrenbayne and Boho, the possibility of producing wood products will be discussed or expanded on. The discussion will not be limited to plantations on the break of slope but for any location where commercial or semi commercial forestry is possible. This includes any recharge areas.

What makes a good forestry species for Warrenbayne and Boho

This section will outline what makes a good forestry species for the Warrenbayne and Boho areas and following on is an outline of which species work best considering the issues raised. The main considerations are:

What are the market options

In the end the outcome is dependent on what farm grown logs can be used for. Markets for logs are essential.

Stem straightness

When discussing commercial forestry not all species are suitable for one practical reason – stem straightness. It is essential for efficient harvesting, log handling and processing most products, particularly high value solid wood products.

Ease of management

For farming communities with time constraints ease of management of forestry trees must be high on the list of essentials, especially for small plantations where commercial thinning may be unviable. All forestry species that grow well in the Warrenbayne and Boho areas have issues with branches at wider spacing and they often must be removed by mechanical pruning if log quality is to be maximized or to even attract a processor to use them.

The species with best potential

Radiata pine

The greatest opportunity for commercial returns is with Radiata pine (*Pinus radiata*). The Northeast is well set up for processing the species from pulp mills, chipping plants and sawmilling of small diametre 'commercial' thinning to peeling and sawmilling large diametre logs from final harvests. These industries are set up around Hancock's Victoria Plantations, some of which can be seen from Warrenbayne and Boho at the top of the escarpment – just beyond the high recharge areas. There are also a number of large private growers who supply these industries.

The commercial thinning option is one that only the largest growers can do viably and it has only limited opportunity for the smaller forestry plots like those in Warrenbayne and Warrenbayne West. The best opportunity for small growers is to produce the best quality logs possible. That means removing unwanted trees (thinning) as early as possible to promote diametre growth in the best trees and removing branches with mechanical pruning. Tree selection can help with this. Cuttings are available with 'high growth and form ratings'. These cutting are taken from trees with the best growth rates and with the best branching habit which can ultimately make pruning and thinning easier because fewer trees are needed at the start and branches are smaller and easier to remove. There are examples of these trees in a few locations in Warrenbayne.

Even with the best trees pruning and thinning is a lot of work and requires some skill to get it right but it will produce high quality, large diametre logs free of internal defects that demand the highest prices in current markets.

The Australian Forest Growers also have a stand certification system in place that certifies when pruning took place and the size of the unpruned core of the log which will help marketing at a later date.

The final stocking rate in these stands will depend on the site where they are grown. The existing stands in Warrenbayne and Warrenbayne West may be overstocked and diametre growth appears to have slowed in recent years and some drought deaths are occurring on lower rainfall sites. Those on Glenisla which has the highest rainfall at about 800 mm average are currently spaced at 300 to 320 trees per hectare and a reduction to 220 to 250 is being considered. Monitoring growth over the next few years will determine what happens.

How viable harvesting will be is yet to be determined. The existing harvesting industry is not set up for small scale harvesting and it is expensive with the large equipment currently in use. The best opportunity will be with specialist small scale operations similar to some that exist overseas and co-ordinated harvesting of two or more plantations will help reduce costs. We are probably at least 10 and perhaps 15 years away from that situation.

Hardwood markets – an opportunity for southern blue gum

All of the other species are hardwoods and they are a much greater marketing challenge than Radiata pine. The difficulty with hardwoods is that the current hardwood sawmilling industry in Northeast Victoria is not set up to market products from most of the species that are growing well in the Warrenbayne Boho area.

Numerous trails conducted in existing sawmills including at the Ryan and McNulty Sawmill in Benalla show there is no doubt plantation grown logs can be processed efficiently if diameter requirements of the mills are met and management has been targeted to produce the right type of logs. Plantation grown trees of southern blue gum, spotted gum, Sydney blue gum and flooded gum are in fact currently being processed commercially either in Australia or overseas. For example, southern blue gum is being processed in large quantities in northern Spain and flooded gum in Brazil and some other South American countries. Both species produce high value products that are accepted in markets around the world.

As far as the existing industry is concerned southern blue gum is the species that best matches their current supplies of mountain ash so it may become a substitute - in Tasmania this is happening to a limited extent already in an industry that is being adjusted out of the native ash and mixed species forests by the Tasmanian government. The challenge with the other species is new markets need to be developed and that is costly and few mills are willing to take a new resource on unless they can be guaranteed a certain supply to cover their market set up expenses.

One opportunity that may be the best outcome for some hardwood species is the development of small scale on site processing systems to supply local markets with 'specialty timbers' from environmentally acceptable sources.

Southern blue gum

As already discussed southern blue gum hasn't performed well in many locations and without good management they aren't the best looking trees around. However, there are a few locations where survival has been good where water is available from the watertable. With good thinning and pruning it can have a place in the higher rainfall areas of Warrenbayne if nowhere else. There is also an opportunity to select better performing trees from the three sub-species that grow across southern Australia.

As far as the timber goes it is one of the harder species to process. The main challenge is it can be hard to dry and industry drying methods like those used at the Ryan and McNulty sawmill are needed. The wood does have a range of uses from engineering to appearance applications and its blond colour is sought after particularly in the Asian market. One of the main attributes of southern blue gum is it is the best species for production of high quality paper and that means residues from sawmills and veneer mills have a ready market.

On a slight downside being similar in appearance to current native forest timber in southern Australia is not always a good thing. In southwest Western Australia in the early 2000's there was an oversupply of 'ash type' timber from Tasmania on the west coast where southern blue gum is grown extensively. This temporarily made processing southern blue gum unviable as product value dropped substantially on the local market (Bob Hingston, Department of Agriculture and Food WA *personal communication*). However, this situation was a one off and it is unlikely to be repeated.

Spotted gum

There are a few related species of spotted gum, the main one found in Warrenbayne and Boho is *Corymbia maculata* or *Eucalyptus maculata* (depending on which taxonomy book you look up). It is the stand out species of all the hardwoods growing in Warrenbayne and Boho. It grows on all sites

from the high rocky recharge areas to the lower slopes even right up to the edge of saline areas. It is drought tolerant and is known to tolerate fire. Frost sensitivity may be an issue but trees sourced from the Victorian provenance may help and planting at higher elevations can get them above the worst frosts.

As far as management goes it is one of the easiest of all of the species to manage. It shed branches well and trials at CSIRO in 35 year old trees sourced from the southern Murray Darling Basin have shown that pruning is not essential - but log quality will be improved with light mechanical pruning.

Well grown 30 year old spotted gum and red iron bark that were given room to grow with thinning, and branches controlled with light mechanical pruning. These trees can produce high quality logs for products like furniture and flooring.

Spotted gum is also easy to process. Log splitting can be an issue during sawmilling but this is thought to be linked to heavy uneven branching that may occur on the edge of plantations. As far as drying sawn wood goes it is one of the easiest of all eucalypts to dry.

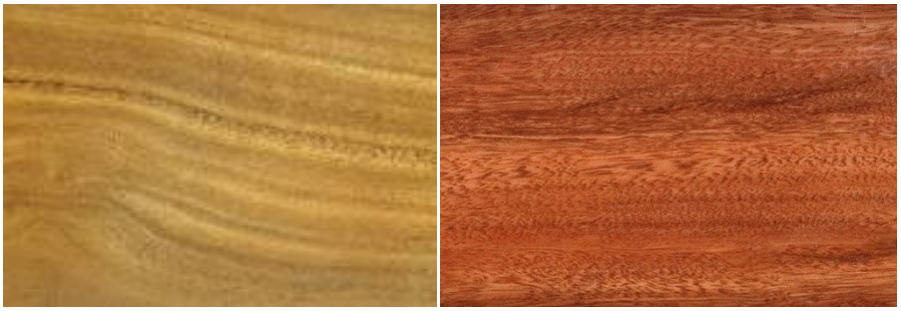
It is suited to a range of high value appearance and engineering products and can be used for furniture with careful selection of glues for fixing joints and it is ideal for flooring and it can be used outdoors as decking, and thinnings and forest residues are good for firewood.

Spotted gum flooring produced by the author from young plantation grown trees managed with careful thinning and pruning to promote growth and processed with conventional sawing and drying methods that could be done on farm.

Red iron bark and sugar gum

Red iron bark (*Eucalyptus sideroxylon* subsp. *sideroxylon*) and sugar gum (*E. cladocalyx*) grow well in the Warrenbayne Boho area, with the caution that red iron bark doesn't tolerate competition as much as some species and sugar gum has some frost sensitivity. Both of these issues can easily be overcome with good management and site selection. They are both found growing in all parts of the landscape from the rocky high recharge areas to the lower slopes and they are well represented in plantations in neighbouring regions in the southern Murray Darling Basin.

Both species fit in the same category as spotted gum in that they shed branches reasonably well and so are easy to manage and require only little pruning and can produce good quality logs without pruning with the right management. While they both have problems with stem straightness, that can be overcome with careful selection of trees as they grow and thinning out unwanted trees for firewood.



Sugar gum on the left and red iron bark from unpruned plantations in the Southern Murray darling Basin.

Like spotted gum both species are easy to process and perhaps they are easier to saw than spotted gum being less prone to splitting.

The wood of sugar gum is very dense and dries slowly. Its density means it also has great strength and it is good for engineering timbers that also have an appearance function. It can be used for furniture, flooring and decking.

Red iron bark is very easy to dry and the dark red timber is highly valued for furniture, flooring and a range of appearance applications.

Flooded gum and Sydney blue gum

Flooded gum (*Eucalyptus grandis*) and Sydney blue gum (*E. saligna*) and perhaps the closely related southern mahogany gum (*E. botryoides*) are all similar in terms of management, site selection and their wood. They are more restricted in where they are found growing in the Warrenbayne Boho area than spotted gum, sugar gum and red iron bark. They are restricted primarily to the area around the break of slope where they have survived well and tolerate drought. They are all sensitive to the frosts of the Warrenbayne Boho area but there are numerous plantations around to show they can be easily established.

They all shed branches to some extent but pruning is warranted. As far as stem straightness both flooded gum and Sydney blue gum have excellent form. The southern mahogany gum found in the

area isn't as good but there is a suspicion they are all from the same source. This is probably an issue with seed selection rather than a problem with the species in general.

Processing is reasonably easy in comparison to the ash eucalypts and southern blue gum. Being closely related species the wood of flooded gum, Sydney blue gum and southern mahogany gum is very similar in appearance. It is used around the world for engineering and appearance applications.

Flooded gum flooring

Silky oak and river sheoak

Silky oak (*Grevillea robusta*) and river sheoak (*Cassuarina cunninghamiana*) are common in the Warrenbayne and Boho areas and they grow well in all parts of the landscape and tolerate drought. Frost may be an issue with silky oak but that can be overcome by planting above the worst of the frosts. Even so it is growing in some frosty areas.

The management needed for both species is probably more intensive than for all of the species discussed so far with the exception of radiate pine and southern blue gum. They certainly need some attention to branching. Both species produce wood that is easy to process and it has great decorative value because of the characteristic 'figure' in the wood.

Silky oak

River sheoak

Carbon

On a final note carbon is another product that shouldn't be forgotten. If you can't get paid directly for the carbon you can at least have the knowledge that carbon dioxide is being taken from the atmosphere and stored as carbon in the organic matter in the trees as they grow. It may also prove useful when it comes time for harvest and sale of logs as an incentive to a potential purchaser of the final product.

Trees take from the atmosphere the green house gas carbon dioxide and convert it into the organic component in wood and other plant tissue. The carbon in the organic matter accumulates in quite large amounts as trees grow and when wood is converted to final products the carbon is held in the wood for the life of the product while the replanted forest starts accumulating carbon again. So a plantation established as a management tool for a high watertable can also have the added environmental benefit of permanently taking carbon dioxide from the atmosphere.

The amount of carbon dioxide is not insignificant. On Glenisla in Warrenbayne it is estimated that the 15 hectares of planted trees as they grow take at least 100 tonne of carbon dioxide from the atmosphere each year. Most of the plantations have been growing well now for 25 years or more and so there is now 2,500 tonnes less carbon dioxide in the atmosphere than would be the case if it hadn't been decided to try and manage the watertables on Glenisla.

Appendix One: General Groundwater Observation Bores

General Groundwater monitoring boes in the Warrenbayne Boho area						
Bore #	Elevation	Bore Depth	Monitored	Last level	Current trend	Location
	(m)	(m)		(m)		
118847	203.11	11.00	1982-2016	-2.76	2.38	Dobson Rd
118846	203.11	19.00	1982-2016	-2.61	2.96	Dobson Rd
WRK957009	201.34	16.81	1992-2012	-7.51	2.66	Dobson Rd
118852	206.48	19.00	1982-2012	-2.88	1.39	West of Dobson Rd
WRK957008	202.87	17.85	1992-2016	-5.22	2.17	West of Dobson Rd
WRK957007	198.03	21.64	1992-2016	-17.69	3.25	West of Dobson Rd
WRK957006	204.80	17.84	1992-2012	-9.36	0.05	West of Benalla-Warrenbayne Rd
WRK957010	199.64	10.45	1994-2016	-3.22	-1.15	North of the Dobsons Rd hills
118862	195.67	10.00	1989-2016	-2.69	3.45	East of the Dobsons Rd hills
118861	189.04	11.00	1989-2016	-1.94	0.11	East of the Dobsons Rd hills
WRK956930	181.48	6.00	2004-2016	-4.45	-1.60	Dobson Rd Midland Hwy
118855	235.83	15.00	1984-2016	-2.61	-1.01	South of Baddaginnie Swanpool Rd
124346	243.46	25.00	1995	-3.79	NA	Harrison Rd Catchment
124347	253.05	27.50	1995	-0.60	NA	Harrison Rd Catchment
124348	247.26	25.00	1995	-2.17	NA	Harrison Rd Catchment
WRK957018	271.07	15.89	1993-2016	-11.31	-5.30	Harrison Rd Catchment
WRK957019	267.81	19.77	1994-2016	-9.88	-4.07	Harrison Rd Catchment
WRK957021	257.42	10.43	1995-2016	-3.87	-2.59	Harrison Rd Catchment
WRK957022	268.81	4.86	1994-2016	-4.68	-0.28	Harrison Rd Catchment
WRK958091	247.75	5.00	1994-2017	-2.99	-0.34	Harrison Rd Catchment
128898	243.85	19.50	1997	-0.50	NA	main Warrenbayne valey
128897	243.73	25.00	1997	-2.61	NA	main Warrenbayne valey
128899	249.18	25.00	1997	-3.56	NA	main Warrenbayne valey
128900	237.90	8.50	1997	-2.19	NA	main Warrenbayne valey
WRK957005	236.24	6.73	1994-2010	-1.96	NA	main Warrenbayne valey
WRK957032	223.86		1991-2016	-3.75	-1.83	main Warrenbayne valey
118853	229.03	19.00	1982-2016	-8.03	-0.81	main Warrenbayne valey
118854	229.16	6.00	1982-2012	-5.91	-0.98	main Warrenbayne valey
WRK957004	221.29	8.69	1995-2016	-3.93	-0.31	main Warrenbayne valey
118859	213.14	8.00	1989-2015	-5.47	-1.52	main Warrenbayne valey
118860	215.59	8.00	1989-2016	-2.32	0.04	main Warrenbayne valey
WRK957003	206.71	10.20	1992-2016	-4.41	-1.02	main Warrenbayne valey
118858	208.48	10.00	1989-2016	-2.96	-0.01	main Warrenbayne valey
WRK956924	239.42	3.36	1994-2005	-3.08	NA	Warrenbayne West
WRK956925	236.79	12.37	1995-2005	-4.10	NA	Warrenbayne West
116695	238.36	40.00	1987-2016	-10.55	-5.50	Warrenbayne West
116696	232.72	50.00	1987-2016	-10.01	-2.07	Warrenbayne West
WRK957033	227.44	4.10	1995-2004	-4.10	NA	Warrenbayne West
WRK957034	226.68	18.95	1994-2004	-11.10	NA	Warrenbayne West
WRK957035	225.08	21.60	1994-2016	-8.77	-3.43	Warrenbayne West
WRK957036	224.55	49.19	2000-2016	-7.21	-3.53	Warrenbayne West
WRK957037	222.95	24.59	1994-2016	-5.71	-3.76	Warrenbayne West
WRK957038	221.94	19.97	1994-2014	-5.92	-2.69	Warrenbayne West
WRK956928	214.09	19.00	2008-2016	-14.31	3.51	Warrenbayne West
WRK957011	209.75	21.48	1992-1996	-21.48	NA	Warrenbayne West
WRK957002	203.00	21.27	1995-2015	-10.85	1.17	Warrenbayne West
118673	208.06	9.00	1988-2017	-7.98	-5.90	Warrenbayne West
118671	203.18	7.00	1989-2017	-2.74	-1.39	Warrenbayne West
118672	205.85		1988-2016	-6.00	-2.60	Warrenbayne West
WRK957013	194.83	16.90	1993-2017	-10.39	0.77	Warrenbayne West
118670	212.23		2005	-3.73	NA	Boho
WRK957015	194.58	9.49	1993-2012	-2.08	0.42	Boho
118674	193.93	17.00	1988-2016	-4.60	0.72	Boho
WRK957014	188.59	5.72	1994-	-5.72	NA	Boho
WRK957017	186.12	17.96	1999-2012	-15.08	2.11	Boho
WRK957016	201.17	12.45	1992-2016	-4.27	-0.89	Boho
118645	228.21		1982-1994	0.18	0.18	Boho
WRK956937	229.21	6.00	2000-2012	-1.19	0.18	Boho