PRELIMINARY ASSESSMENT OF RAINFALL AND GROUNDWATER TRENDS IN AREAS OF WANDOO

WATER AND RIVERS COMMISSION REPORT
SLUI 27
2003
SALINITY AND LAND USE IMPACTS

Water and Rivers Commission

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by

Robin Smith

Resource Science Division

Water and Rivers Commission

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REPORT NO. SLUI 27

APRIL 2003

Acknowledgments

This report was prepared with assistance from Mohammed Bari, Lidia Boniecka, Philip Commander, Renee Dixon, Drew Haswell (CALM), Geoff Mauger, Jack Mercer (Bushcare), Paul Raper (AgWA), Martin Revell, Phil Roberts, Simon Rodgers, John Ruprecht, Tim Sparks, Melanie Strawbridge, Roger Underwood, Alex Waterhouse and Lin Ye.

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Recommended Reference

The recommended reference for this publication is: SMITH, RA 2003, *Preliminary assessment of rainfall and groundwater trends in areas of wandoo*, Western Australia, Water and Rivers Commission, Salinity and Land Use Impacts Series Report SLUI 27.

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ISBN 1-920849-29
ISSN 1447-7394

April, 2003

Cover photograph:

Wandoo in salt scald on Abercorn Road, Helena River catchment, by Robin Smith

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Summary

Examination of 100-year rainfall records in the wandoo zone of southwest Western Australia shows a long-term decline since the 1970s. The lower mean rainfall and few above-average rainfall years have led to lower groundwater recharge. On fully timbered slopes the long-term decline in rainfall appears to have resulted in groundwater (and soil moisture) decline. Soil moisture, although not always correlated with soil water or groundwater level, is expected to have generally declined in response to decreased rainfall. Soil moisture (in the unsaturated zone above the watertable) is believed to be the source of most water transpired by wandoo, especially where wandoo occur above saline groundwater. Wandoo Crown Decline and Death (WCDD) is not directly related to and the result solely of groundwater decline. A broader survey of wandoo occurrence incorporating examination of site characteristics might be required to ascertain other factors in wandoo death.

Wandoo (*Eucalyptus wandoo* Blakely) and powderbark wandoo (*E. accedens* W. Fitzg.) trees (Brooker and Hopper, 1992) occur discontinuously in the western Wheatbelt and eastern Darling Range including the water supply catchments of the Helena and Collie Rivers (Fig. 1). Wandoo woodlands are generally located on soils that have accumulated significant salt storage (from rainfall). Where they occur the groundwater is also commonly saline and the watertables range in depth from shallow to more than 30 m. Therefore wandoos appear to be predominantly non-phreatophytic, drawing water from the unsaturated zone but using some shallow groundwater. They survive waterlogging on non-saline well-drained soils but succumb quickly to salinity (Fig. 2a). The occurrence of WCDD in the eastern part of the Helena River catchment (Fig. 2b) has the potential to effect thinning of the overstorey. This would increase groundwater recharge and mobilise salt to the surface in groundwater seepage, further threatening both the wandoos and the salinity at Mundaring Weir.

The York LCDC (2002) reports that, since the late 1980s, occurrence of WCDD has been observed widely in the southwest of Western Australia. To determine whether changes in either groundwater level or soil water storage may be a factor contributing to WCDD, groundwater hydrographs were examined in 4 areas of monitoring adjacent to wandoo woodland, and soil water balances calculated in 2 of these areas. This assessment is seen as a useful preliminary to any multi-agency investigation of WCDD, similar to that coordinated by the Tuart Response Group.

Winter rainfall has variously declined at most of these sites since 1975. At the northernmost sites groundwater levels have declined under both trees and pasture, with very little recharge. The wandoo planted at Flynn's Farm remain free of WCDD above saline groundwater while the watertable has declined by 7 m, from 3 to 10 m depth, in 19 years. Trend analyses of two lengthy hydrographs confirms the linkage with rainfall deficits and also indicates evaporative use varied with tree growth and thinning. From the latter it may be surmised that the wandoo are not taking all the soil water in winter or after thinning. Although there is no correlation between groundwater level and soil moisture, the water levels at Flynn's Farm peak each winter in response to groundwater recharge, indicating both that water has passed through the soil profile and that it has reached soil capacity each year. The water level is similarly declining with small winter peaks in undisturbed wandoo in Lemon Catchment where the health of wandoo in undisturbed bush should be examined for other causal factors in WCDD.

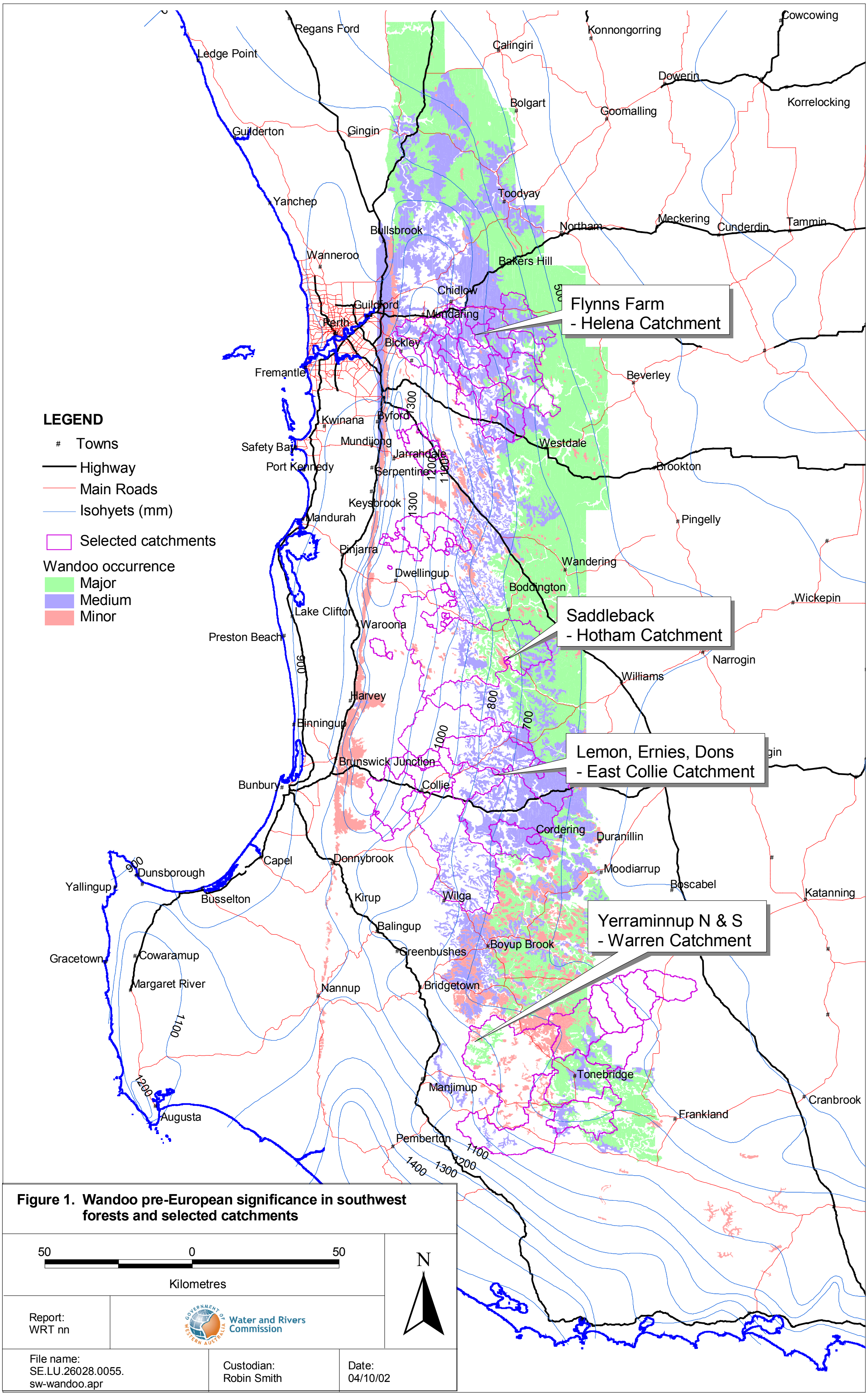


Figure 1. Wandoo pre-European significance in southwest forests and selected catchments

1 Introduction

1.1 Purpose and scope

Wandoo (*Eucalyptus wandoo)* and powderbark wandoo (*E. accedens)* are two of the most important of Western Australian eucalypts (York LCDC, 2002). These slow-growing eucalypt hardwoods have been widely exploited for fuel and timber and have a significant ecological role. The use of 'wandoo' for both their common names causes some confusion, as they are from separate taxonomic groups. The wandoos occur as major overstorey trees in the drier parts of State forest (Fig. 1) and are key components of remnant bushland and paddock trees on farmland in the western Wheatbelt (Brokker and Kleinig, 1990). They survive mainly in reserves (Capill, 1984) as the agricultural land has been largely (93%) cleared (Mercer, 1991). Wandoo is the major tree species in the drier (i.e. high salt hazard) sections of the metropolitan water supply catchment areas, and is thus a key feature in salinity control for Perth's and the Goldfields water supplies. The relationship between clearing and salinity was observed and reported by the early 1900s (Bleazby, 1917; Wood, 1924). Figure 1 is based on wandoo vegetation systems mapping classifications in the southwest of Western Australia by Mattiske Consulting (CALM, 1998).

Water quality in the Helena Reservoir suffered from a three-fold increase in stream salinity when 8000 ha of trees were ringbarked in the western high rainfall section of the catchment in 1903 to increase runoff to Mundaring Weir (Croton and Dalton, 1999). Other activities subsequently implicated in salinity increases have been: logging most of the catchment in the period 1950–1975 to provide firewood for the Wundowie charcoal-iron plant, and wandoo for industrial extracts; clearing for agriculture on the 5% of the catchment which is privately owned; and the death of some vegetation due to dieback disease caused by *Phytophthora cinnamomi*. Land Monitor (2000) indicates significant shallow groundwater and potential dryland salinity in valley floors in the eastern Helena River catchment.

Wandoo Crown Decline and Death (WCDD) affects wandoo and powderbark wandoo throughout the range of both species in Western Australia although the exact distribution is not known. It was first noticed in the late 1950s to early 1960s (Mercer, 1991), but by the mid to late 1990s had become widespread (York LCDC, 2002). It is especially noticeable in the northeastern section of the Helena River catchment (Fig. 2b) and on farmland west of York, Beverley, Brookton and Pingelly. WCDD is also noticeable within a 60 km radius around Cranbrook, including the Stirling Range and Tambellup Shire, and straddling the length of Albany Highway (Mercer, 2002, pers. comm.). Wills *et al*. (2000, 2001) examined several mixed vegetation communities and reported that WCDD was extensive only on the wandoos and occurred in many areas in southwest Western Australia. They concluded that most trees will probably survive should favourable rainfall conditions prevail and recommended that wandoo water use physiology, stand responses to site conditions, and regeneration ecology be investigated. WCDD is thus a factor in ongoing attrition of wandoo (Mercer, 2002, pers. comm.), and declining rainfall may be a contributing factor.

This report examines rainfall and groundwater records for evidence that long-term change of those parameters, together with soil moisture, are factors in WCDD. The York LCDC (2002) pointed out that larger scale climatic records did not appear to support the view of declining rainfall in the wandoo zone, and local observations have not indicated any improvement in the problem during wet years, so detailed

Figure 2a. Wandoo death from dryland salinity near Abercorn Road, Flynn's Farm

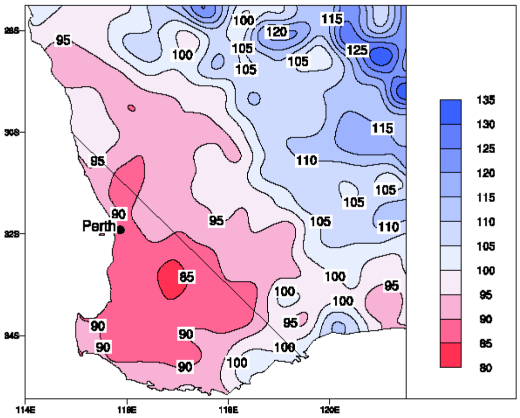


Figure 3. Pattern of rainfall change as a percentage of May–October rainfall for the last 25 years compared to the previous 50 years (Indian Ocean Climate Initiative Panel, 2002, Fig. 2)

Figure 2b. Wandoo Crown Decline in trees of varied age near Wundabiniring Brook in Mundaring catchment

micro-climatic or groundwater studies might be needed. However the May–October rainfall for the last quarter century as a percentage of the previous 50 years (Indian Ocean Climate Initiative Panel, 2002) actually does reveal a seasonal shift in rainfall with significant decreases in the southwest of Western Australia (Fig. 3). Within the zone of wandoo occurrence long-term groundwater records are available from the Helena, Hotham, East Collie and Warren Rivers catchments (Fig. 1).

1.2 Hydrogeological setting

Wandoos occur mainly in the Yilgarn–Southwest Groundwater Province, for much of which hydrogeological maps are available (Smith *et al*., 1999). In this province the basement comprises granitoid rock, gneiss, rare dolerite and quartz dykes and is up to 30% exposed on the slopes and higher ground together with about 30% colluvium. The province comprises an ancient plateau incised by rivers flowing west and south respectively to the Perth Basin and the Bremer Basin.

Sand plain and laterite occupy a significant portion of the higher landscape. The valleys contain alluvium and sediments typically 70 m thick where they infill palaeodrainage channels. The regolith (sediments and weathered bedrock) thickness is thus variable and typically about 30 m thick. These factors underpin the variety of soil compositions evident in the landscape. Although the bedrock is uniform over large areas, local variations combined with differences in landform and climate have produced a variety of extensive soil types.

Salt has accumulated in the regolith over long periods through the evapotranspiration of rainfall. The depth to groundwater ranged from about 2 m near valley floors to 30 m (where present) for upper slopes. The clearing of native vegetation has changed the cycle of evapotranspiration and groundwater recharge and resulted in lower evapotranspiration, increased infiltration of rainfall, increased groundwater recharge and rising groundwater levels, albeit unevenly across the landscape. Consequently, in lowlying areas, groundwater is within 2 m of the surface and therefore discharging by evaporation. This evaporation from the shallow watertable concentrates the salts in groundwater near the surface and accumulates them in the soil. From the near surface these salts enter streams.

All sites for which groundwater hydrographs were considered for analysis in this study are located on regolith above weathered crystalline bedrock largely comprising granites and gneisses. The regolith varies in composition (although mainly clayey with minor grit and laterite) and thickness (typically 30 m, but up to 70 m). The sites have moderate relief and contain low order streams. They are variously vegetated and in most the groundwater levels have declined latterly.

1.3 Wandoo occurrence

Wandoo and powderbark wandoo trees occur discontinuously in the western Wheatbelt between Mingenew and Albany (REX'96, 1996). Their best development is from between Darkan (about 30 km east of Lemon catchment) and Quindanning (about 30 km south-southeast of Boddington) to Toodyay, in broad shallow valleys or on low ridges (Fig. 1). Wandoos tends to grow on well-drained, acidic dark-brown loamy sands or sandy loams containing some gravel over a clay sub-soil. Wandoo is adaptable to most well-drained soils in full or filtered sun. Although moderate drought-tolerance indicates this species has a low water requirement, it is considered by some to be a high water user as it is tolerant of seasonal waterlogging (Mercer, 2002, pers. comm.). It has a life span of more than 75 years. One of the oldest recorded ages for a wandoo individual, in Dale, was 385 years (Mercer, 2002, pers. comm.; CALM, 1991, pers. comm.). It is slightly salt tolerant, probably surviving above saline watertables and in salty regolith by intercepting fresh soil moisture with its significant root system. Wandoo will survive where cropping is no longer viable due to waterlogging and salinity (Mercer, 2002, pers. comm.).

Wandoo is a species of woodland or open-forest formation (Boland *et al*., 1992). Associated eucalypt species in the western part of its distribution include powderbark wandoo, jarrah (*E. marginata*) and marri (*Corymbia calophylla*). In the wheatlands to the east it may be associated with salmon gum (*E. salmonophloia*). Wandoo replaced jarrah on shallow soils in the eastern Darling Range. It is predominant in the 400–700 mm/a rainfall zone and is less competitive in the higher rainfall zone unless on or near the Darling Scarp (where soils are shallow and well drained). The occurrence and density of wandoo, together with powderbark wandoo where present, are shown in Figure 1. Figure 1 indicates both their significance in the overstorey and absence from some streamlines, and that wandoo is a significant overstorey species in the eastern parts of the Helena and Collie water supply catchments. The detailed distributions of wandoo have not been mapped and the distribution of WCDD is only now being mapped (Mercer, 2002, pers. comm.).

1.4 Wandoo death

Since the late 1980s widespread rapid defoliation of wandoos has been observed in association with WCDD (York LCDC, 2002). The main species in decline is *E. wandoo* subs. *wandoo* (Southern wandoo). *E. cappillosa* (Wheatbelt wandoo that belongs to the same taxonomic group as Southern wandoo and occurs further east), appeared unaffected (Mercer, 2002, pers. comm.).

WCDD develops rapidly from year 1, when the upper and outer twigs in the crown die. These are replaced in year 2 by epicormic shoots, which also subsequently die. The widespread rapid defoliation and branch death leads to some tree deaths, with more as decline persists (Mercer, 2002, pers. comm.). Over a period of 3–5 years the tree may move from apparently unaffected to dead.

Whole stands are affected and the problem occurs randomly in the uplands, on the wide flats, on granitic or lateritic soils, in forests and isolated paddock trees. Large, older trees appear to be affected first; later in the same area, younger trees begin to suffer and then die. Mercer (2002, pers. comm.) found there was little impact on regeneration stands and on some unaffected older trees scattered throughout the landscape.

There are indications that WCDD is cyclic and while some wandoo die, most have recovered (Mercer, 2002, pers. comm.). For instance in the Stirling Range, decline after a hot fire in 1994 appeared to devastate epicormic growth of affected trees in 1994–5. In 2002 recovery with no cyclical ongoing decline pattern was evident but 24% of the trees had died. However in areas where decline appeared in the late 1990s the loss of epicormic growth is continuing. A new decline event has just begun in Woogenilup, southeast of Cranbrook between the Stirling and Porongurup Ranges. WCDD was not recorded here beforehand, except maybe at Kamballup to the east on Chester Pass Road.

Various fungal pathogens exist in forests and woodlands in Australia and overseas (Mercer, 1991). The most severe are root rot fungi such as *Phytophthora* and *Armillaria* species with the most common of the latter being *Armillaria luteobubalina* Watling and Kile. It spreads most rapidly after disturbance, such as logging activities where left-over stumps provide a larger food base.

From 38 infected and 28 non-infected sites surveyed in the southwest of Western Australia, Shearer *et al.* (1997) determined that the average mortality of wandoo trees was 47% in disease centres of intermediate impact and 66% for high impact areas. These wandoo woodlands contained 26 host species for *A. luteobubalina*.

The severity of *A. luteobubalina* infection was not strongly related to site factors (Shearer *et al.*, 1997). Impact type was not related to slope, aspect, topographic position and local landscape. High impact disease centres mainly occurred low in the landscape possibly because these positions are watergaining and would provide a moist environment favourable for *A. luteobubalina* survival and infection. Impact was significantly associated with soil texture. Coarse-textured soils were mainly associated with non-infested sites compared with the finer-textured loamy soils of intermediate impact centres, but high impact sites were equally divided between the two texture types. Shearer's work seems to associate *A. luteobubalina* with WCDD but confirmation may require further work. Mercer (2002, pers. comm.). thought *A. luteobubalina* impact was often significant on wandoo but only over restricted areas.

1.5 Dry spell suspected in tree deaths

There is a widespread perception that the wandoo zone is experiencing a severe dry spell, and that this has greatly affected groundwater availability for trees (York LCDC, 2002). This gives rise to concerns that severe decline in *groundwater in the root zone* generally leads to decline and death of trees, or stresses trees to the point at which they are unable to withstand secondary stressors such as pathogens, insects, or environmental stresses such as frost, fire, and herbicide drift (York LCDC, 2002). The term *groundwater in the root zone* used by the York LCDC could rightly be interpreted to mean soil water (reducing) or to (increasing) depth to groundwater. The two can be correlated but this is not always the case.

The occurrence of WCDD has some parallels with Tuart deaths reported by the Tuart Response Group (2002). Commander (2002) undertook analyses of bore water level records for the impact of CDFM (cumulative deficit from mean) rainfall, groundwater abstraction and aquifer parameters including transmissivity. The Tuart Response Group (2002) concluded that groundwater level decline was not a factor, as:

- Tuart decline is occurring remote from groundwater abstraction.
- Watertables at Yalgorup are stabilised to the levels in nearby lakes and the ocean through high aquifer transmissivity, even though Tuart Decline has occurred in this locality.
- Tuart has the capacity to grow on upland sites where there is considerable depth to groundwater.

This report explores the relationship of wandoo with groundwater, particularly examining hydrograph and rainfall records in the western wandoo zone for:

- watertable depth, range and trends
- groundwater salinity
- soil moisture
- rainfall trends.

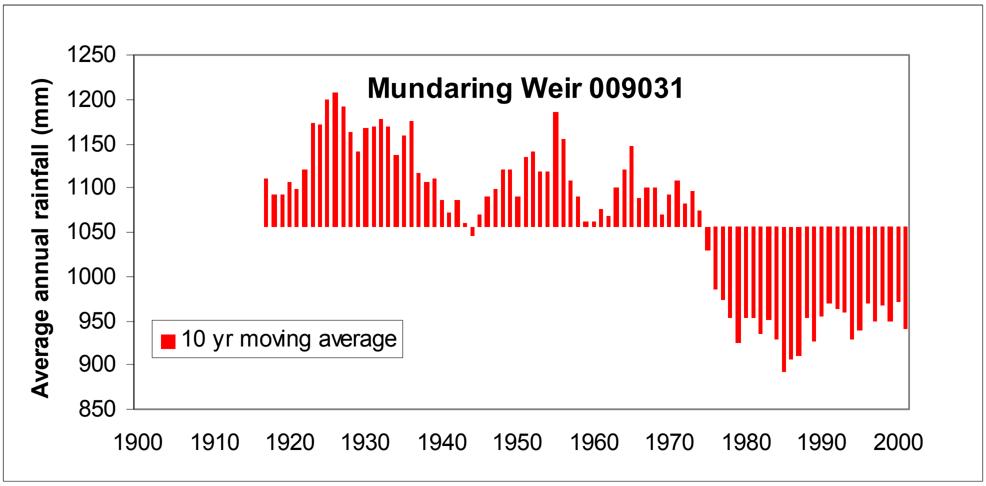
Other questions arising out of the (York LCDC, 2002) workshop report on wandoo decline are noted in the Appendix.

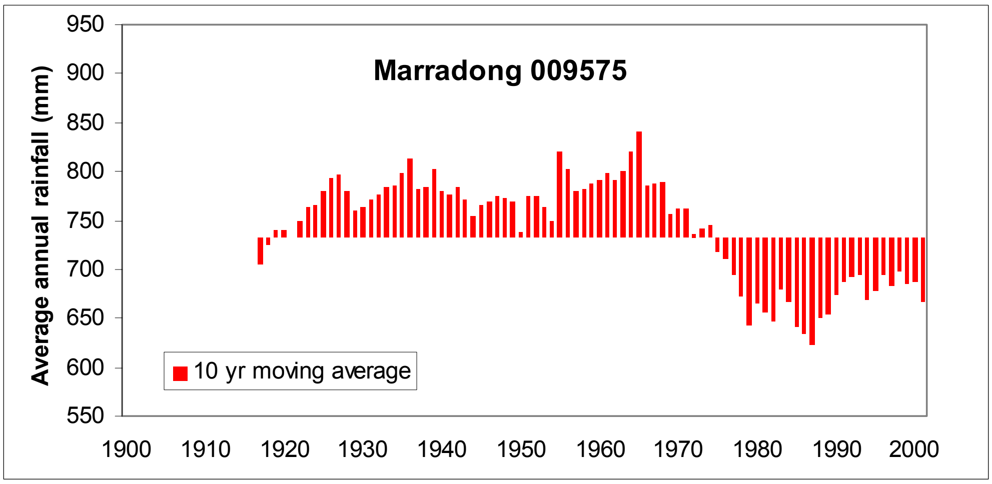
2 Rainfall analysis

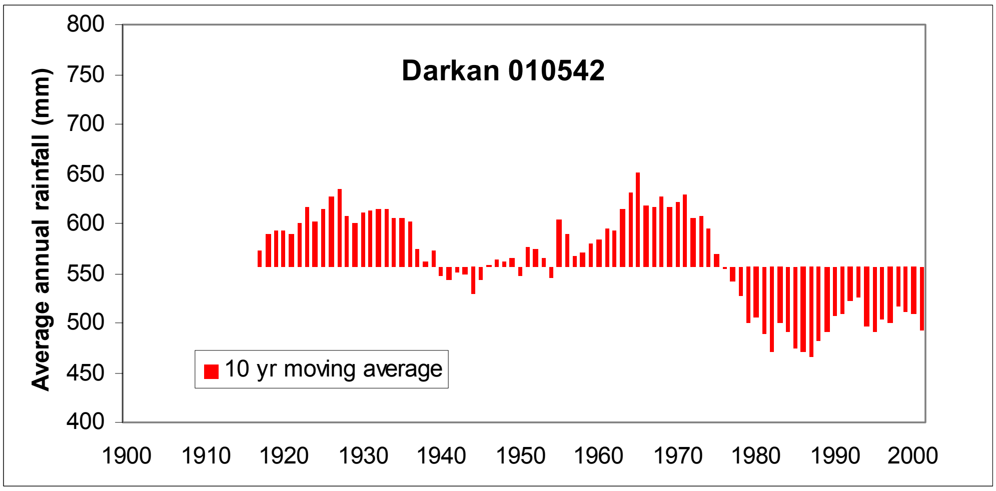
Rainfall records at or near sites with long-term groundwater monitoring and wandoo woodland were checked for declining trends in the 10-year rolling average, particularly since the 1970s. Throughout the southwest, rainfall has declined since the 1970s with the greatest decrease along and east of the high rainfall zone inland from the Darling Scarp (Fig. 3). For Jarrahdale, Perth and Rottnest Island the decline extends back to 1930 (Ruprecht *et al*., 1996). The decline in rainfall in the Helena River catchment, evident in rainfall plots for two stations east of Mundaring (Croton and Dalton, 1999, Figs 4 & 16), is shown in the 10-year backward-looking average for Mundaring Weir in Figure 4. Rainfall records for Marradong (about 7 km south of Boddington but with fewer recording gaps) and Darkan also show this decline from the 1970s (Figs. 5 & 6).

Examination of Figures 4–6 suggests the decline in rainfall may be apparent from shorter records in the forest and experimental catchments. However such records, including Ernies and Dons subcatchments of the East Collie River (including simulation prior to 1974 for use in Mauger *et al*., 2001), do not clearly reveal the decline in rainfall from the 1970s. So to illustrate the rainfall decline in areas of WCDD over the last 20 years would require at least 40–70 years of records for an individual rainfall station.

In above-average high rainfall years, experienced up to the 1970s, groundwater was recharged episodically. Under the subsequent prevailing regime of below average rainfall both the soil moisture and groundwater recharge are likely to have been lowered.







Figures 4–6. Annual rainfall averages for Mundaring Weir, Marradong and Darkan

3 Hydrograph & soil water variation

3.1 Introduction

Analysis of selected groundwater hydrographs can be used to determine the role of rainfall recharge, evapotranspiration and drainage (at the recording site). Groundwater records longer than 3 years within the area of significant, and stable remnant, wandoo vegetation occurrence (Fig. 1) are mostly from the forest and experimental catchments. These catchments have multiple monitoring sites with about 20 years of monthly groundwater level records. Records were obtained for analysis at 9 experimental sites in 4 catchment areas (Fig. 1). These are in the Helena River catchment (Flynn's Farm and the adjoining Wellbucket site), the Hotham River bauxite sites at Saddleback (Hunt A & B, also known as Tunnel Road and Bee Farm), the East Collie River catchment (Lemon, Ernies and Dons) and the Warren River catchment (Yerraminnup - North and South). The groundwater hydrographs within the first three catchments were examined as these are lower-rainfall areas of prime wandoo occurrence. In addition, the soil water balance at Flynn's Farm was examined using the AgET recharge calculator. Croton & Croton (in prep.) carried out preliminary analyses of hydrographs at Bee Farm and Tunnel Road but consider the data not accurate.

However groundwater is not uniform across the landscape so its role in WCDD could be irregular both at the local and regional scale. The analysis (see note in Appendix) explains the variations in groundwater hydrographs by accounting for fluctuations in rainfall and evapotranspiration. Trends should be explicable in terms of factors such as specific yield (specific yield reflects lithology and converts the change in water storage/yield to a change in water level) variation in the regolith, land use change, clearing, fire, tree growth and decline, and forest thinning. The analysis can take account of identified changes, reducing or eliminating the unexplained component of the hydrographs. Sudden change in wandoo health, and related factors such as remnant vegetation density, would be detectable in a controlled environment.

3.2 Flynn's Farm

Flynn's Farm is a WRC freehold property in the Helena River catchment, and in particular within the Mundaring Weir Catchment proclaimed under the *Country Areas Water Supply Act 1947*. It comprised two farms prior to acquisition of the land in 1971 and is managed by the Water Corporation under delegation from the WRC for Goldfields water quality protection purposes. Of 770 hectares cleared for farming, about 330 hectares have been planted to pines and about 380 hectares to eucalypts. Approximately half of the farm area was cleared, probably progressively in the early part of the period 1957–1971. Flynn's Landscape and Flynn's Hillslope (Fig. 7) were 98 and 100% cleared, respectively (Bari and Boyd, 1994). Revegetation of about half of the cleared area saw river redgum (*E. camaldulensis*) and wandoo planted in 1977 at Flynn's Landscape and 1978/79 at Flynn's Hillslope.

Wandoo decline is reported in the district but has not been observed in Flynn's Farm (Environs Consulting Pty Ltd, in prep.). Hydrographs have already been reviewed by Bari *et al*. (1990) in contrasting the water use under agroforestry with the water use under pasture. The long-term average

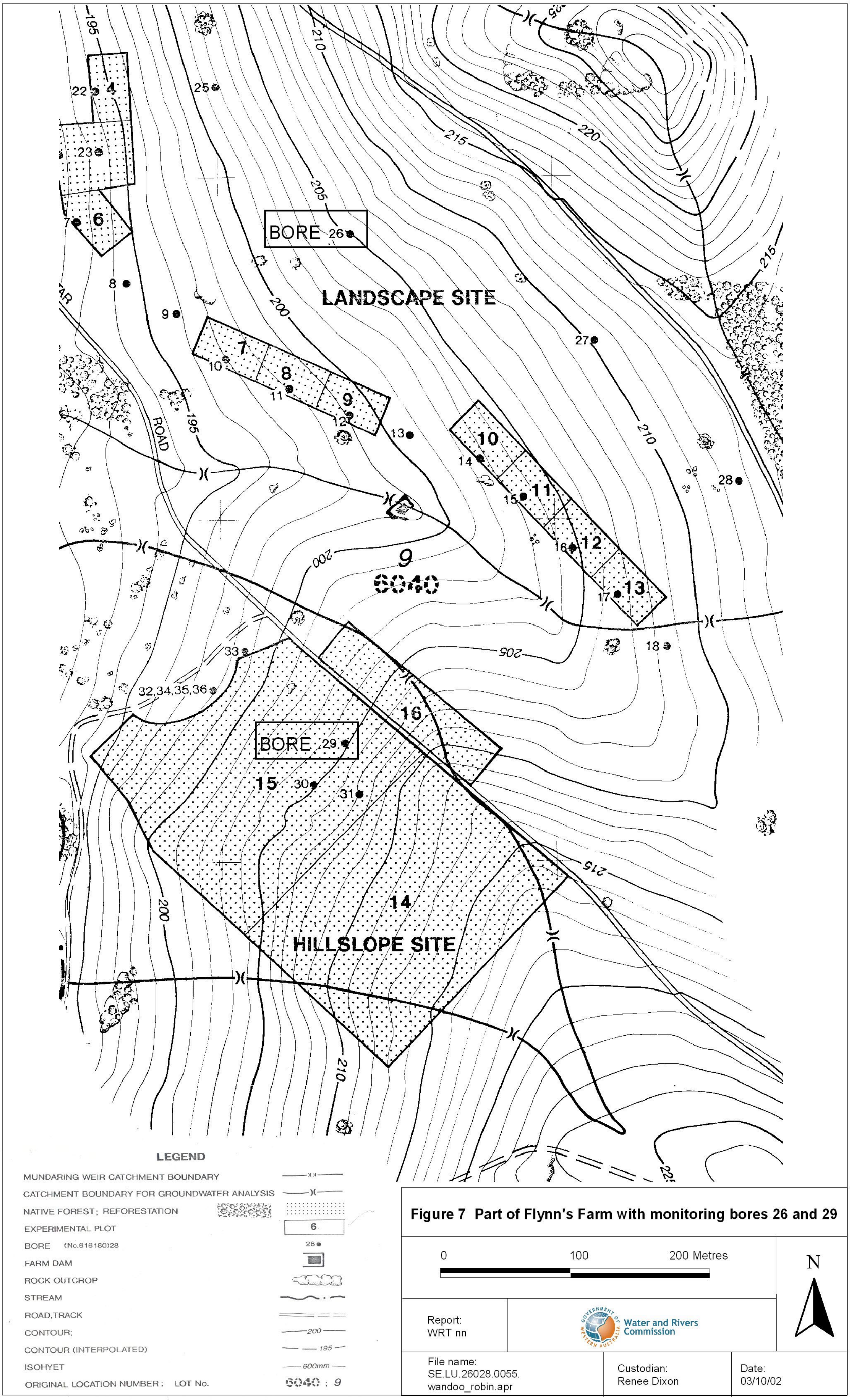


Figure 7 Part of Flynn's Farm with monitoring bores 26 and 29

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Table 1. **Stem density and crown cover at Flynn's Farm hydrograph boresites 26 & 29 (based on Bari and Boyd, 1994)**

Site	***Stem density***			***Area planted***	***Crown cover %***		***Initial DTWL***	***Groundwater salinity (mg/L TSS)***	
	Initial	***1986***	***1993***	***%***	***1987***	***1993***	***mbns***	**Initial**	***1990***
Landscape	670	500	425	8	43	59	2.1	6880	7220
Hillslope	1200	1000	480	54	29	36	1.0	8340	6920

annual rainfall of about 725 mm is much lower than at Mundaring Weir (Fig. 4). Mean annual rainfall in the Helena River catchment decreases west to east from about 1100 to 700 mm. Potential evapotranspiration is about 1400 mm/a, increasing to the northeast. The groundwater is saline (Table 1).

Analysis was undertaken using the hydrographs for monitoring bore 61618029 ('29') located in Plot 15 on Flynn's Hillslope and 61618026 ('26') located in adjoining pasture on Flynn's Landscape (Fig. 7). Hydrograph 29 is located in plantation river redgum 40 m northwest from an adjoining wandoo plantation that covers most of the upslope subcatchment. These two adjoining sections of Flynn's Farm were regarded as a control for a third section, Flynn's Agroforestry, several kilometres to the northwest (Bari et al., 1990), thinned between 1982 and 1988. Morgan (1999, Plan BM85-1-1) indicates that the 1978 plantings on Flynn's Farm included river redgum on Flynn's Hillslope Plots 15 & 16 and wandoo on adjoining Plot 14 and in plots on Flynn's Landscape. Plots 14–16 were much thinned from 1250 to 500 stems/ha by 1987 and were similar in crown cover (39%) and stem density (498/ha) to that surveyed in 1993 (Morgan, 1999) and possibly 1988 (Table 1). Indeed the analysis of hydrograph 29 strongly confirms Flynn's Hillslope was thinned in the period 1984–1988 by indicating a lapse in the otherwise increasing evaporation factor (Fig. 8). The plantation and pasture site analyses were expected to differ mainly in the interception of recharge by their respective vegetation.

3.2.1 Analysis of hydrograph 61618029

The surface elevation at bore 61618029 is 205 mAHD (Fig. 7). At the start of hydrograph 29 the water level appeared to still be rising, possibly in response to clearing of the site post-1957 (Fig. 8). The water level thereafter declined to be 10 mbns (metres below natural surface) in 1996-97, down by approximately 7 m from about 3 mbns (202 mAHD) in 1977-78. For the steadiest part of this decline, 1990–1994 inclusive, the average annual rainfall was 653 mm. The rainfall coefficient from the analysis indicates that this rainfall would cause the water level to rise 3.03 m/a (metres/annum). The rise was offset by evaporation (3.01 m/a) and a time component (0.47 m/a), leaving an average decline of 0.45 m/a. These conditions, and therefore a similar rate of water level decline, are considered likely during the post-monitoring period, 1998 to present. This would put the water level at about 12 mbns by 2002. An average annual rainfall of about 740 mm would be required to offset this decline. Alternatively, management that reduced the evapotranspiration component by 15% would also offset this decline. Although not yet limiting water level decline, depth to bedrock is less than 20 m (Bari *et al*., 1990).

The evaporation factor applied in the analysis of hydrograph 29 increased from 0.40 to 1.0 by late 1980 with a subsequent peak of 1.40 in 1997 (Fig. 8). These variations are inferred to indicate changes in vegetation density and growth. The amplitude of water level variation with change in water storage in the saturated profile did not require the analysis to vary the specific yield factor from 1.0.

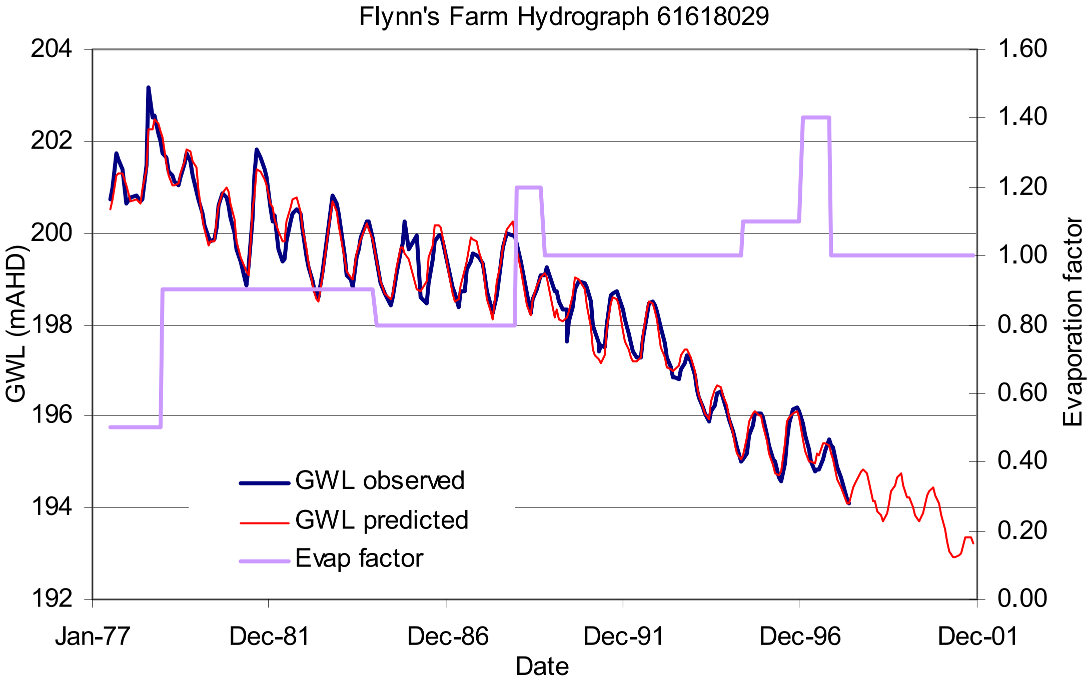

Figure 8. Flynn's Farm bore 61618029 in plantation

3.2.2 Analysis of hydrograph 61618026

The surface elevation at bore 61618026 is 205 mAHD (Fig. 7). Hydrograph 26 shows a slightly rising water level at about 4 mbns (201 mAHD) in the period 1977–1983, then a decline of about 2.5 m to be 6.5 mbns in 1996-97 (Fig. 9). Again 1990–1994 is within the steadiest part of this decline and has the same rainfall applied as on the adjoining site 29. The rainfall coefficient from the analysis indicates that this rainfall would cause the water level to rise 2.28 m/a. The rise was offset by much lower evaporation (1.06 m/a) than at site 29 and a higher time component (1.22 m/a), leaving an average decline of 0.00 m/a. These conditions, and therefore a similar rate of water level decline, are considered likely during the post-monitoring period, 1997 to present. The trend analyses to 1998 indicate recharge was insufficient to raise the watertable even under the pasture adjoining the eucalypts on Flynn's Farm.

The hydrograph does appear to be slowly declining, but step-wise, comprising periods where the evaporation factor is changed. The evaporation factor applied in the analysis of hydrograph 26 increased from 0.70 to 1.0 by mid-1983 with subsequent oscillations between 1.40 and 0.40 from 1988 to 1997 (Fig. 9). These variations are inferred to indicate changes in water use related to vegetation density and growth. The higher time component at site 26 is taken to indicate that, with the higher water level, there is a higher rate of water loss by lateral drainage of groundwater in the water balance.

Lateral drainage has the effect of inducing a downward head differential between the watertable and the screened interval in the monitoring bore. It is evidenced by the presence of springs along the creeks. Both hydrographs 29 and 26 show annual recharge followed by declines, possibly indicating vertical withdrawal from the watertable by trees (29) and pasture (26) in which case the watertable at site 26 would have to be within 2 m of the surface. As both hydrographs rise each year in response to recharge, the soil moisture in the unsaturated zones above the watertable did reach field capacity, although probably for a lesser period given the decreased rainfall.

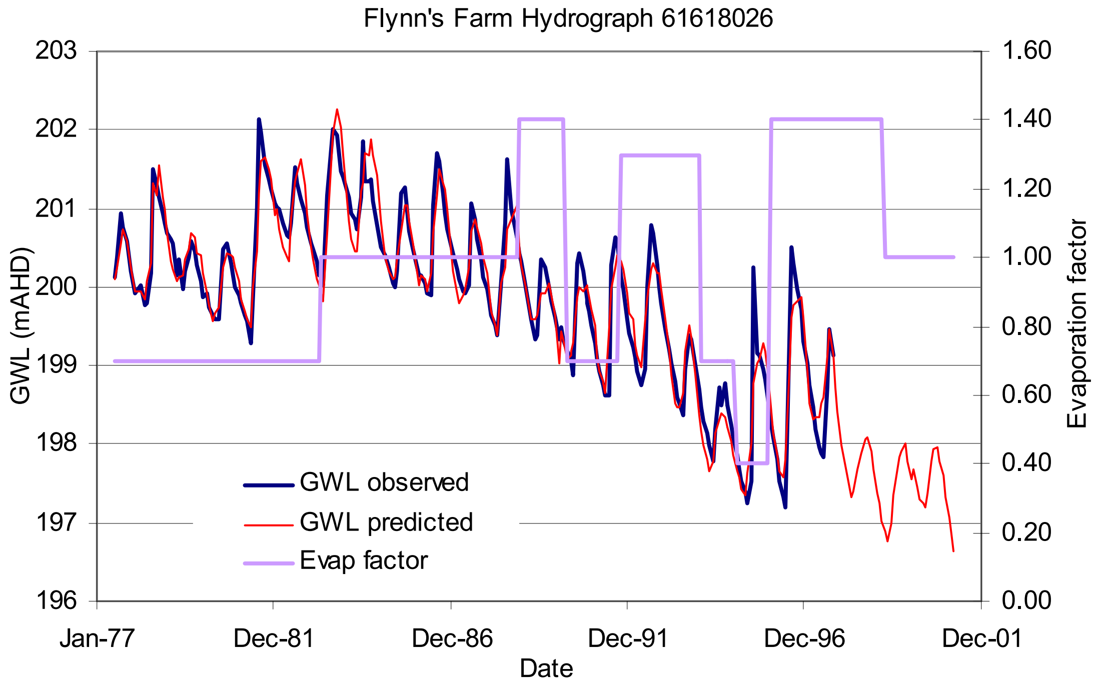

Figure 9. Flynn's Farm bore 61618026 in pasture

3.3 Lemon Catchment

Lemon Catchment, draining west to the Collie River East Branch, was established in 1971 as part of an experiment to understand and quantify stream salinity generation (Figs 1 & 10). Wandoo is a significant component of the remnant vegetation in the upper vegetated part of this small catchment and may not have been impacted by WCDD. The 344 ha catchment was instrumented and monitored prior to logging and clearing of the western 53% in 1976–77.

In the cleared part of Lemon catchment monitoring bores indicate water levels rose. In the vegetated eastern half deep bore 61218704 (8704) shows a 4-m decline at a diminishing rate over 23 years (Fig. 11). Mauger et al. (2001) reviewed hydrographs in the Collie catchment but the trend analysis for hydrograph 8704 was not published. As the hydrograph shows little seasonal variation it is considered not a good prospect for trend analysis. The accompanying shallow bore 61218720 (8720) has a truncated record as, due to its shallow construction and water level also falling, it was sporadically dry prior to 1992 and intermittently dry thereafter. Trend analysis revealed a decline of the groundwater level in monitoring bore 8704 (since 1974) in response to decreasing rainfall (Fig. 11).

The surface elevation at bore 61618704 is 326 mAHD (Fig. 10). Even at the start of hydrograph 8704 the water level appeared to be falling, although the early data appear to contain a 1.5 m datum error. The water level thereafter declined to be 30 mbns (metres below natural surface) in 1998, down by approximately 4 m from about 26 mbns (200 mAHD) in 1973. The average rainfall of 685 mm/a from 1973–1998 (long-term average about 700 mm/a) is at the low end of the range for the Collie catchment (about 600–1200 mm east–west. Potential evapotranspiration is between 1400 and 1600 mm/a, increasing to the east). The rainfall coefficient from the analysis indicates that this rainfall would cause the water level to rise 0.46 m/a. The rise was offset by evaporation (0.42 m/a) and a time component (0.23 m/a), leaving an average decline of 0.19 m/a. These conditions do not persist in later data which indicate the water level trend becoming horizontal but beginning to oscillate from 1989. To offset the decline (of 0.19 m/a) would require an average annual rainfall of about 920 mm or management that reduced the evaporation (specifically water uptake by vegetation) component by 45%.

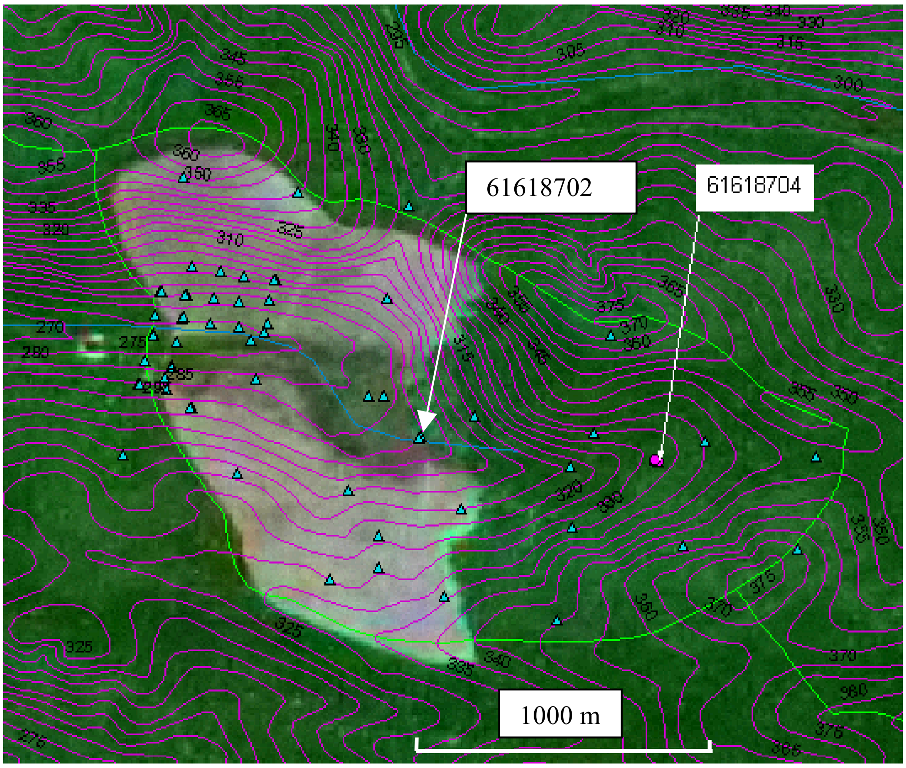

Figure 10. Lemon catchment with monitoring bore 8704

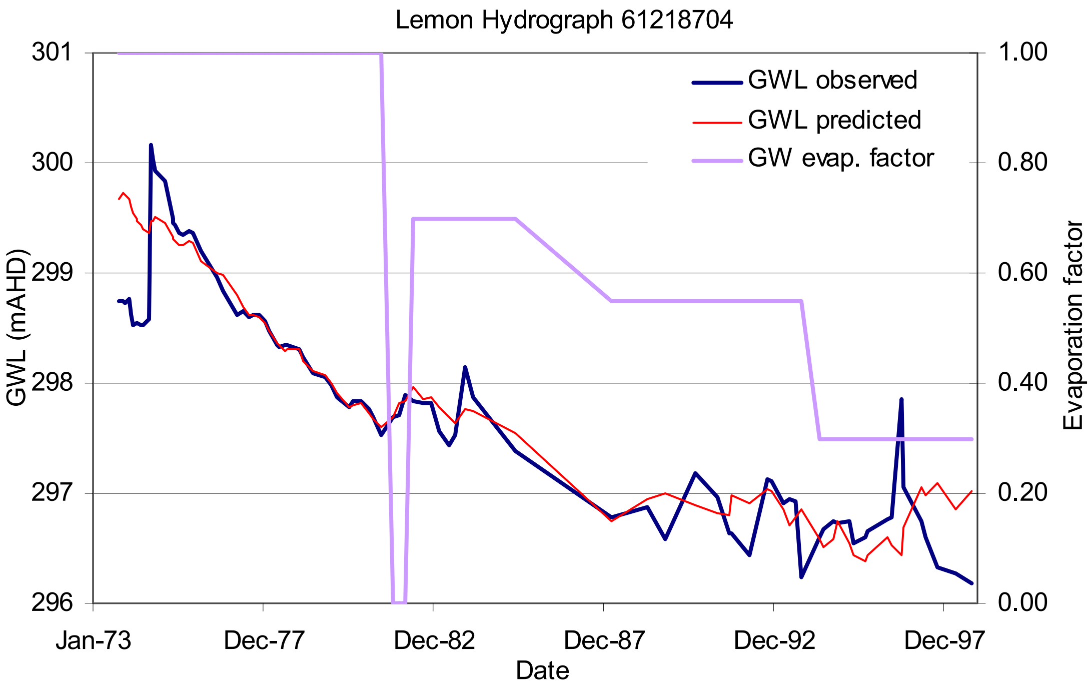

Figure 11. Lemon catchment bore 8704 in remnant wandoo vegetation

The evaporation factor applied in the analysis of hydrograph 8704 decreased from 1.0 to 0.40 paralleling the decline in **rainfall** (Fig. 11). These variations may indicate responding changes in **vegetation** density, health and growth. In particular, as eucalypts shed leaves in response to reduced water availability, they may represent lower use (evaporation) of groundwater by trees. The amplitude of water level variation since 1989, with change in water storage in the saturated profile, required the analysis to vary the specific yield factor from 1.0 to 0.4 below 297.5 mAHD. A third possibility is that the time component (**drainage**) has slowed due to water levels rising in the lower valley. In support of this, the hydrograph for bore 61218702 (Fig. 10), where the water level has risen about 23 m to be within a metre of the surface, shows synchronous oscillations also commencing in 1989 and increasing in amplitude. The surface elevation of 290 m AHD is within a few metres of the water level in bore 61218704 so apparently pressure builds up with recharge and then declines annually with evaporative discharge from the watertable lower in the valley.

3.4 Soil water balance

The soil water balance at Flynn's Farm was examined by using AgET (Argent 1999), a simple cascading bucket recharge calculator. This software has been updated periodically by extending the rainfall data, currently allowing analysis for the period 1954–1993. After initialising for rainfall at Mundaring (about 6 km north of the Mundaring Weir site used above) to be factored to a mean annual rainfall of 653 mm, AgET indicates that changing from pasture to eucalypts in 1978 reduces runoff and deep flow (groundwater recharge) from 17 to 8 and 216 to 11 mm/a respectively, increases evapotranspiration from 377 to 583 mm/a and reduces the change in storage from 57 to 24 mm/a. These results indicate very little recharge beneath (mature) eucalypt forest. By variation of the soil profile and other parameters it is possible to tweak the small amount of annual recharge indicated by the small rise in groundwater level (Raper, 2002, pers. comm.). AgET only runs eucalypts as annuals and treats them as instantly fully mature, so there is some inaccuracy in these figures for the several years of immature growth. As a variability check the Flynn's scenario was run for the (slightly higher rainfall and lower evapotranspiration) Lemon catchment. The results differ only slightly between the two sites with runoff and deep flow (groundwater recharge) reducing from 32 to 20 and 263 to 59 mm/a respectively, evapotranspiration increasing from 352 to 533 mm/a and the change in storage reducing from 63 to 24 mm/a.

Finally, rainfall data for Mundaring up to 2001 was used to extend the run of AgET for eucalypts, in the soil profile used for both Flynn's Farm and Lemon catchment, from 1954–1993 to 2001, ie beyond 40 years apparently needed to discern rainfall shift. The indicator of annual change in soil moisture in the (effective) root zone (set to 4 m), shown as a 10-year backward looking average (Fig. 12), shows no net change after the 1970s. This suggests that, despite the decline in long-term rainfall (Figs 3–6) and groundwater level (Figs 8, 9 & 11), the soil moisture has not declined since the 1970s.

4 Discussion

4.1 Rainfall

Long-term (100-year) rainfall records for Mundaring Weir, Marradong and Darkan indicate the rainfall (shift or) decline over the last 25 years (Figs 4–6) identified by the Indian Ocean Climate Initiative Panel (2002). The forest and experimental catchments in areas of prime wandoo occurrence examined in this study are too short or ambiguous to confirm this decline. Where the latter have been extended by simulation of the nearest suitable long-term records for use in modelling the declining trend is replicated.

4.2 Groundwater

To take account of rainfall variations, trend analysis can be attempted with simple records of watertable peaks and troughs for just 2 years, however much more satisfactory analysis is possible with 3–4 years of daily to monthly water level records. One priority of this investigation came to be the analysis and interpretation of (several) groundwater hydrographs. Such records are available for many bores in the southwest of Western Australia, however the sites are clustered in experimental and WRC catchments within the western, forest occurrences of wandoo. The sites considered for trend analysis occur in a range of landscape positions that are also a factor influencing their groundwater levels. Of those monitored catchments within the extent of prime wandoo woodlands, an even smaller subset contain bores located within remnant vegetation or replanted eucalypts. Their records however are more than long enough, about 20 years in length, for trend analysis to determine particularly the recharge and evapotranspiration factors of their water balances, but also the lag in response, amplitude and drainage.

At Flynn's Farm the evaporative demand varied between seasons and years. Evapotranspiration under plantation (river redgum adjoining wandoo) increased as the trees matured and, since 1978, has drawn down the water level below 2 mbns. Even though the water level has declined over the last 25 years, it is still not thought to be at the pre-clearing level. Since 1990 the plantation trees have been capable of suppressing the groundwater level for an average annual rainfall of 700 mm, which equates to a 50 mm/a buffer in the current rainfall condition. This buffer could also be effective were the plantation to be thinned by tree death. The adjoining grazed pasture site, however, has no buffer to wetter years, although water levels even here declined slightly in response to the decline in rainfall.

At Lemon catchment the water level under natural wandoo woodland declined through the 1970s and 1980s but from 1989 to 1998 oscillated annually without declining. Groundwater drainage may now be restricted by the greatly increased water storage immediately downslope beneath the cleared half of the catchment.

Although monthly groundwater level records such as those from Flynn's Farm and Lemon catchment constitute an invaluable data resource, the plantation setting of the former is neither natural nor affected by WCDD. In Lemon catchment, where the status of WCDD has not been ascertained, the water level has a declining trend under native vegetation. These catchments are west of both the 650 mm isohyet, within the zone of significant rainfall decrease (Fig. 3) and the major area of (pre-clearing) wandoo distribution in the Wheatbelt (Fig. 1).

These settings are useful even though they may not fully represent remnant wandoo vegetation with associated ecological processes (including understorey, range of age cohorts, and WCDD). To extrapolate the results to other sites in wandoo woodland, consideration must also be given to rainfall and reliability, groundwater level and trend, regolith composition, clearing history, current stem density and associated vegetation.

4.3 Wandoo

Wandoo woodland occurs in a range of topographic positions where the depth to water ranges up to about 30 m but not on streamlines where saline groundwater discharges. At Flynn's Farm healthy wandoos about 25 years old are near site 29 where the saline (about 8000 mg/L) watertable declined from 3 to 10 mbns in the first 19 years. Wandoo does not survive dryland salinity - the saline waterlogging associated with rising and discharging groundwater (Fig. 2a). Rising groundwater levels, waterlogging and dryland salinity resulting from clearing native vegetation have resulted in rapid local wandoo death within the eastern Helena catchment near Wundabiniring Brook, Abercorn Road and Wariin Well. Wandoo influence water levels by withdrawing water from the unsaturated zone above the watertable. They appear to be non-phreatophytic but, as they are able to be established and survive on soil moisture in thin (non-saline or unsaturated) regolith, they may partly draw from the watertable. There is no apparent incidence of WCDD with the water level change at Flynn's Farm. So for nearby areas of WCDD experiencing a similar rainfall decline, such as Wundabiniring Brook (Fig. 2b) and Wariin Well, there must be an interaction with other factors.

WCDD has the effect of thinning the overstorey. The established WCDD in the eastern part of the Helena River catchment could lead to increasing groundwater recharge and subsequent mobilisation of salt to the surface in groundwater seepage. If the wandoo were significantly affected or rainfalls were to increase, the additional groundwater recharge could lead to increased salinity-related wandoo deaths (Fig. 2a) and also increase salinity at Mundaring Weir. As wandoo is the major tree species in the drier (i.e. saltier) sections of the metropolitan water supply catchment areas, it is a key feature in salinity control for Perth's and the Goldfields water supplies.

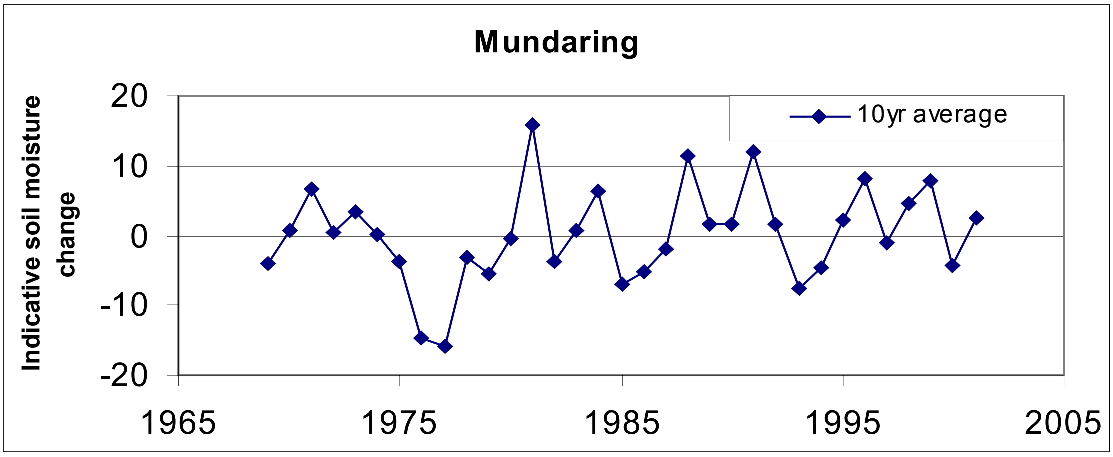

Figure 12. Modelled soil moisture change beneath eucalypts

5 Conclusions

The major conclusions from this study relate to rainfall decline, groundwater response, soil moisture and use by wandoo, and possible factors in wandoo death.

A long-term decline in rainfall has been observed in the wandoo zone of southwest Western Australia. Ten-year backward-looking averages indicate this trend for the 100-year records at Mundaring Weir, Marradong and Darkan. Since the 1970s the lower mean rainfall and few above-average rainfall years have led to lower groundwater recharge.

Groundwater hydrograph records are available for a number of forest and experimental sites in the west of the wandoo zone of southwest Western Australia. Groundwater levels are not in uniform decline as they are responding to other factors that influence evapotranspiration and groundwater recharge, including vegetation change, position in the landscape and downslope groundwater levels. On fully timbered slopes the long-term decline in rainfall appears to have resulted in groundwater (and soil moisture) decline.

Soil moisture, although not always correlated with soil water or groundwater level, is expected to have generally declined in response to decreased rainfall. An indicator of annual soil moisture change calculated by AgET appeared stable since the 1970s. Soil moisture (in the unsaturated zone above the watertable) is believed to be the source of most water transpired by wandoo, especially where wandoo occur above saline groundwater.

WCDD is not directly related to and the result of groundwater decline. At Flynn's Farm plantation eucalypts remain healthy despite their use of soil-water corresponding with both a decline in rainfall and a fall in groundwater level. The health of remnant wandoo bushland at Lemon catchment where groundwater levels have similarly declined has not been ascertained. A broader survey of wandoo occurrence incorporating examination of site characteristics might be required to ascertain other factors in wandoo death. By including a site with well-recorded hydrology, eg Flynn's Farm, Wellbucket Catchment, and Lemon Catchment, the survey might also cover the hydrological factors potentially affecting the condition of the vegetation and highlighted in this report, namely rainfall, groundwater levels and soil moisture.

References

Argent, RM 1994, *AgET water balance calculator*, Agriculture Western and University of Melbourne, version 2.1.

Bari, MA & Boyd, DW 1994, *A review of reforestation experiments to control land and stream salinity in Western Australia*, Western Australia Water Authority, Water Resources Directorate. Report WS 141, 30+p.

Bari, MA, Schofield, NJ & Boyd, DW 1990, *Groundwater level and salinity response under agroforestry at Flynn's Farm in the Darling Range of Western Australia*, Western Australia Water Authority, Report WS 72, 58p.

Bleazby, R 1917, *Railway water-supplies in Western Australia—difficulties caused by salt in soil*, in *Minutes of Proceedings of the Institution of Civil Engineers with other Selected and Abstracted Papers*, London, Institution, v. 203, Paper no. 4193, p. 394–400.

Boland, DJ, Brooker, MIH, Chippendale, GM, Hall, N, Hyland, BPM, Johnston, RD, Kleinig, DA, in Turner, JD 1992**,** *Forest trees of Australia*, CSIRO, Australia, 4th edition reprint, p.394–399.

Brooker, MIH & Hopper, SD 1992, *A taxonomic revision of Eucalyptus wandoo, E. redunca, and allied species (Eucalyptus series Levispermae Maiden – Myrtaceae) in Western Australia*, Nuytsia, v. 8, 1991–1992, p. 1–195.

Brokker, MIH & Kleinig, DA 1990, *Field guide to Eucalypts—south-western and southern Australia (volume 2)*, Inkata Press, Melbourne & Sydney.

CALM 1998, *Mapping of Vegetation Complexes in the South West forest region of Western Australia*, Western Australia Department of Conservation and Land Management, Information Management Branch, GIS Section, Mattiske Consulting was responsible for the initial review and integration of floristic classifications and the survey work required to map the vegetation complexes.

Capill, LG 1984, *Wandoo woodland conservation—A proposal for a system of ecological reserves in the woodlands of southwestern Australia*, Western Australia Campaign to Save Native Forests, 97p.

Commander, DP 2002, *Hydrological factors involved in tuart decline*, in *Tuart conservation and protection*, Western Australia, Tuart Response Group, Status Report, August 2000, Appendix 8, p. 30–32.

Croton, JT, & Croton, CD in prep., *Groundwater data review for the Bee Farm and Tunnel Rd catchments*, Western Australia, Water & Environmental Consultants, Report to the Water and Rivers Commission, March 2003 draft, 19p.

Croton, JT & Dalton, JA 1999, *Stream salinity response to clearing and revegetation of the Helena Catchment*, Western Australia, Water & Environmental Consultants, Report to the Water and Rivers Commission, 45p.

Environs Consulting Pty Ltd, in prep., *Draft Flynn's Farm management plan*, Western Australia, Environs Consulting Pty Ltd in association with Land Assessment Pty Ltd, 22 July 2002 draft.

Indian Ocean Climate Initiative Panel, 2002, *Climate variability and change in south west Western Australia*, Western Australia Department of Environment Water and Catchment Protection, 34p.

Land Monitor, 2000, *http://www.landmonitor.wa.gov.au/index.html*

Mauger, GW, Bari, M, Boneicka, L, Dixon, RNM, Dogramaci, SS & Platt, J 2001, *Salinity situation statement Collie River*, Western Australia Water and Rivers Commission, Water Resource Technical Report Series No. WRT 29, 108p.

Mercer, J 1991, *The decline of Eucalyptus wandoo Blakely in the Western Australian Wheatbelt area*, Western Australia, Murdoch University, Biological and Environmental Sciences, Honours thesis.

Morgan, B 1999, *Crown cover and stem density measurements at reforestation sites in Mundaring Weir and Wellington Dam catchments*, Western Australia Water and Rivers Commission, Report on a technical survey (unpublished).

REX'96, 1996, *Revegetation Expert System [Computer Software CD-ROM]*, Developed by Agriculture Western Australia, Conservation and Land Management (WA), Greening Australia (WA) and Robin Road Software (SA). Sydney, New South Wales: PCWARE Australia.

Ruprecht, JK, Bates, BC & Stokes, RA, eds, 1996, *Climate Variability and Water Resources Workshop*, Western Australia Water and Rivers Commission, Water Resources Technical Report Series No. WRT 5.

Ruprecht, JK & Schofield, NJ 1991, *The effect of partial clearing on the hydrology and salinity of Lemon catchment*, Western Australia Water Authority, Water Resources Directorate Report No. WS 74, 25p.

Shearer, BL, Byrne, A, Dillon, M & Buehrig, R 1997, *Distribution of Armillaria luteobubalina and its impact on community diversity and structure in Eucalyptus wandoo woodland of southern Western Australia*, Australian Journal of Botany, v. 45, no. 1, p. 151–165.

Smith, MG, Ansell, HM & Smith, RA 1999, *A bibliography of published reports on groundwater in Western Australia*, Western Australia, Water and Rivers Commission, Hydrogeology Record Series, Report HG 1, 231p.

Tuart Response Group, 2002, *Tuart conservation and protection*, Western Australia, Tuart Response Group, Status Report, August 2002, 45p.

Wills, A, Tay, F, Stukely, M & Burbridge, T 2000, *Crown decline in wandoo 1999–2000*, Western Australia Department of Conservation and Land Management, 17p.

Wills, A, Stukely, M, Tay, F & Burbridge, T 2001, *Crown decline in wandoo—Supplement 2001*, Western Australia Department of Conservation and Land Management, 29p.

Wood, WE 1924, *Increase of salt in soil and streams following the destruction of native vegetation*, Journal of the Royal Society of Western Australia, v. 10(7), p. 35–47.

WRC, 1999, *Review of the experimental catchments in the Joint Intermediate Rainfall Zone Research Programme*, Western Australia Water and Rivers Commission, Water Resource Technical Series No. WRT 13, 229p. & CD.

York LCDC, 2002, *Action plan to tackle the Wandoo Crown Decline Syndrome*, Western Australia, prepared by the York LCDC following a seminar held at York, April, 2002, 6p.

Appendix

The York LCDC

The York LCDC (2002, Rec 5.7) recommended the Water and Rivers Commission (WRC) undertake a detailed review of local climatic and groundwater trends in the wandoo zone over the last 25 years. Questions arising include:

- Where is wandoo?
- Where is WCDD?
- Where has rainfall declined?
- Has groundwater declined in areas of wandoo?
- Where is there continuous groundwater recording?
- Is groundwater decline linked to WCDD?

If the wandoo zone is experiencing a severe dry spell (at large, local or microclimate scale):

- Is such a dry spell affecting the groundwater availability for trees (no, the trees/wandoo use soil moisture, that depends on rainfall)?
- In what ways does wandoo respond to sustained decline in soil moisture?

Does severe (?) decline in groundwater (again, soil moisture) in the root zone generally lead to:

- decline and death of trees (wandoo)?
- stresses that leave the trees (wandoos) unable to withstand secondary stressors?

Other factors stressing wandoo that could be considered include:

- Is there seed recruitment?
- Are the trees of uniform age?
- Are they old?
- How have they handled (regeneration, etc.) the change in fire regime in the last 200 years?

Mercer (2002, pers. comm.)

Report for CALM to be out by Oct-Nov.

Rapid reconnaissance survey that became heavy work, involving statistics and maps. 30 parameters at 130 sites, 3 transects across the Wheatbelt E-W at York, Narrogin, Cranbrook.

Water deficit – salinity most recognisable but least important, huge loss of leaf and branch biomass (up to 70% of population), only about 10% deaths except for a few sites, little regeneration – probably related to altered fire regime, wandoo do survive.

Cyclic episodes lead to up to 60% deaths for older trees.

Regeneration (<30 y.o.) – trees adapt with minimal impact or not affected.

Healthier crowns higher in the landscape.

Higher impacts occurring in the 450–650 mm rainfall belt, **which coincides** with main wandoo distribution, decline of flooded gums and also higher population density.

Thinks wandoo uses some saline water (at 0.5 m but 170 mS/m is only 1100 mg/L) and more than yates). Wandoo accumulate some Cl in leaves but generally exclude salt. This was shown by comparing soil Na and Cl with foliar Na and Cl at a non-saline and saline site.

Possible fungus attack by Botryasphearia sp. – no proof of this.

Revisited old sites – adapted to drier conditions, became tougher. Wandoo may have more extensive, deeper root systems in the higher landscape.

Affected by fire history – healthier the longer without fires, esp. hot fires. In the long term (several decades), research (Tas. and Vic) shows that eucalypt decline will set in and fire-sensitive spp are more vigorous.

Disease stages – mosaic crown discoloration, then defoliation, branchlets then branches defoliate, epicormic response may or may not be affected by cyclical decline pattern.

Wandoo decline and die in saline flats, some recover with contracted crowns.

After 1994 wild fire, 24% death rate after post-fire epicormic recovery. Redgum Pass 50% killed after similar pattern to 1994 fire, 2000 drought may be implicated in loss of recovering epicorms.

Increased decline between 450 & 650 mm isohyets, less in the >650 mm zone and <450 mm zone.

Little change since 1992 at photographed sites (Boyagin, Noombling, Popanyinning).

Long lateral roots enable wandoo survival in waterlogging.

Wandoo have not succumbed quickly to salinity at Tenterden, with a saltbush understorey.

Some WCDD between Williams and Collie, but showing improvement from an older decline.

Most woodland species in decline. Global tree decline regarded as synchronous at 1988 convention on tree decline.

Notes on Trend Analyses

The process used analyses observed changes in piezometer levels using three independent variables:

- accumulated rainfall accounting for the level rise;
- accumulated pan evaporation contributing to the level fall;
- time contributing to a constant rate of rise or fall.

Accumulated rainfall is modified by losses: runoff, interception, delay and smoothing caused by travelling time of water within the profile before reaching the groundwater table.

Accumulated pan evaporation is adjusted by factors to consider the ratio between pan evaporation and transpiration rates and to account for gross change in transpiration power caused by modifications to vegetation.

The change in piezometer level per unit of net rainfall or transpiration is also dependent on the specific yield of the soil at the watertable. The specific yield may vary with depth below ground.

The analysis requires daily pan evaporation and rainfall data applicable to the site where the analysed piezometer is located and the observed piezometer levels. The calculations were conducted in Microsoft Excel.

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