18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Vegetation type, soil type and shifts and cycles in climate affect deep drainage in eastern Australia

Robinson J.Brett

[1] *Department of Environment and Resource Management, PO Box 318, Toowoomba, Queensland 4350*

Email: brett.robinson@nrw.qld.gov.au

Abstract: Secondary dryland salinity is usually caused by clearing native vegetation and introducing crops and pastures. This damages landscapes and costs more than $1,000 million annually in agricultural production alone. However, in some areas the rate of increase has slowed or there has been a decrease in the extent of dryland salinity. To understand the dynamics of the hydrologic balance in eastern Australia, the HowLeaky?2008 model was used to simulate a range of soil types, climates and vegetation systems. Four soil types were simulated: (i) a Kandosol with plant-available water capacity (PAWC, to 1200mm depth) of 95 mm, (ii) a Chromosol (PAWC of 134 mm), (iii) a Dermosol (PAWC of 143 mm) and (iv) a Vertosol (PAWC of 198 mm). Climate data were extracted from the patched point data website (PPD, http://www.longpaddock.qld.gov.au/silo/) for Wagga Wagga and Moree in New South Wales, and Dalby in Queensland. Simulated vegetation types were annual wheat (sown in late Autumn and harvested in late Spring), and native vegetation.

Groundwater recharge and dryland salinity are derived from deep drainage (soil water that has moved below the reach of roots and soil evaporation). In this study, annual deep drainage and annual rainfall had varying degrees of correlation, depending on the soil and vegetation type. Deep drainage was greatest, and the correlation with rainfall was greatest, for a Kandosol and wheat. With the low plant available water capacity of this soil, on average there is only a small "buffer" of soil moisture storage that reduces deep drainage.

What is less certain than deep drainage being high under crops, is whether there have been cycles or changes in the amount of deep drainage. For wheat and the Kandosol with low PAWC, there were strong temporal cycles in deep drainage at Wagga Wagga. The cycles were weaker at northern sites. Mean deep drainage was also greater at Wagga Wagga and less at Moree and Dalby. Figure 1 shows the cumulative residual standard deviations of deep drainage. There are several long sequences below (falling line) and above (rising line) the mean, suggesting that annual amounts do not vary randomly. Minima occur in the 1940s, 1950s and 1960s for Moree, Wagga Wagga and Dalby respectively. The evidence suggests that climate and deep drainage are subject to periodic changes or cycles, typically lasting from one to a few decades. The sites were different in specific details, and possible associations with climate forcing factors are discussed.

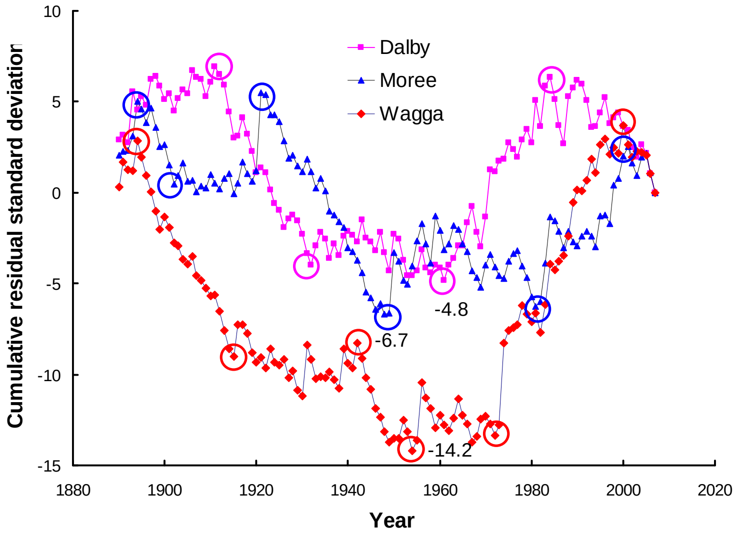

Figure 1. Cumulative residual standard deviations (CRSD) of deep drainage for wheat on a Kandosol at three sites. Historical minima are shown.

Keywords: *Deep drainage, climate change, crop modelling, salinity risk*

1. INTRODUCTION

Dryland salinity has mainly affected southern and western Australia, but there is considerable potential for dryland salinity to also affect northeastern Australia. Clearing native vegetation and growing annual crops and pastures can cause increased deep drainage and subsequent dryland salinity (Peck and Williamson 1987). Areas such as the Liverpool Plains have long been known to have excessive deep drainage under cropping systems and have raised water tables causing dryland salinity (Greiner 1998). Because clearing and the resultant hydrologic imbalances have occurred more recently in Queensland, it is thought that there will be a considerable delay before the full extent of dryland salinity becomes apparent.

Outbreaks of salinity in the inland of northern NSW and southern Queensland have been geographically discontinuous and in many areas have ebbed and flowed with seasonal conditions and land use changes. For example, the Goondoola Basin, 450 km west southwest of Brisbane, developed significant areas of dryland salinity in the 1980s. Since then, a combination of land use change from annual cropping to perennial pastures, and a series of years with lower than average rainfall, have resulted in a reduction of the area affected, and lower water tables.

Abbs and Littleboy (1998) simulated hydrological conditions on the Liverpool Plains with the PERFECT model (Littleboy et al. 1999). They concluded that deep drainage depends on soil type and vegetation type. For example, average annual deep drainage from a Vertosol (Isbell 1996) with high plant-available water capacity (PAWC, mm) was estimated to be 48 mm/year for a traditional long fallow system (2 crops every 3 years), 22 mm/year for opportunity cropping (wheat and sorghum crops planted whenever an opportunity occurs), and 8 mm/year for a fixed lucerne-crop rotation. Soil type had such a large effect that for soils with low PAWC (generally red soils with light texture), only permanent pasture did not have high rates of deep drainage.

Simulation models of the terrestrial water balance are potentially useful for detecting overall system response to complex changes in climate. For example, there is sometimes a higher correlation between the southern oscillation index (SOI) and pasture growth than between the SOI and rainfall. This is known as amplification, and occurs because the SOI affects evaporation and temperature, and perhaps other factors that work in concert.

Estimates of deep drainage from the HowLeaky? model (Rattray et al. 2004) for crops and pastures in southern Queensland suggested that replacing crops with pasture would significantly reduce deep drainage in the Maranoa and on the eastern Downs (Silburn et al. 2007). The benefits of this land use change were much greater for a soil with low PAWC than for a soil with high PAWC.

Deep drainage is obviously affected by climate, and across much of Australia climatic factors such as rainfall, temperature and frost are affected by global forcing factors such as the El Nino – Southern Oscillation phenomenon (Stone and Auliciems 1992; Stone et al. 1996). Given that the extent and rate of dryland salinization have varied over time, it is relevant to ask: Has deep drainage been affected by these global factors?

The aims of this study are to (i) estimate deep drainage for several sites, soils and vegetation types in eastern Australia, (ii) detect climate cycles and changes in rainfall and deep drainage data, should such cycles and changes exist, and (iii) relate climate cycles and changes to climate indices and forcing factors.

Figure 2. The location of Wagga Wagga, Moree and Dalby.

2. METHODS

Wheat cropping and native vegetation were simulated at three sites in a north-south transect: Wagga Wagga (Kooringal station, latitude 35 S, average annual rainfall 570 mm), Moree (Post Office, 30 S, 585 mm) and Dalby (Post Office, 27 S, 600 mm) (Figure 2). Wagga Wagga has year-round rainfall that is winter-effective, Moree has rainfall that is mildly summer dominant and effective all year, and Dalby has rainfall that is strongly summer dominant. A Kandosol (95 mm PAWC to 1200 mm depth), a Chromosol (134 mm), a Dermosol (143 mm) and a Vertosol (198 mm) were simulated. The HowLeaky?2008 model, developed from

HowLeaky? (Rattray et al. 2004), was used to integrate climate, soil, vegetation and other data into estimates of the terrestrial water balance. Of particular interest in this study are changes and cycles in rainfall and deep drainage, as these may be responsible for some of the ebb and flow of dryland salinity observed over the last few decades.

Daily data were summed into annual values and relationships and dependences assessed by two dimensional scatter plots. Cycles and changes in climatic and hydrologic conditions were investigated by plotting the cumulative residual standard deviation (CRSD). This is calculated by summing the standardized residuals ((x-mean)/ standard deviation). These plots are constrained to begin with a small number (the standardized residual in the first year), and finish on zero (because the sum of all residuals equals zero). Rising sections are sequences of years above the average and falling sections are sequences below the mean. Data with skewed frequency distributions, such as daily rainfall data, are more difficult to interpret with this technique because the mean is not central to the distribution and long sequences above or below the mean are usual.

Monte-Carlo analysis shows that sets of 100 random numbers deviate similarly above and below zero, and most sequences deviate within a range of approximately -7 standard deviations (SD) and +7 SD (Figure 3). However, when a change in the mean is included at the mid point of the data, deviations of -5 SD to -15 SD become more frequent, and few deviations occur above zero (Figure 4).

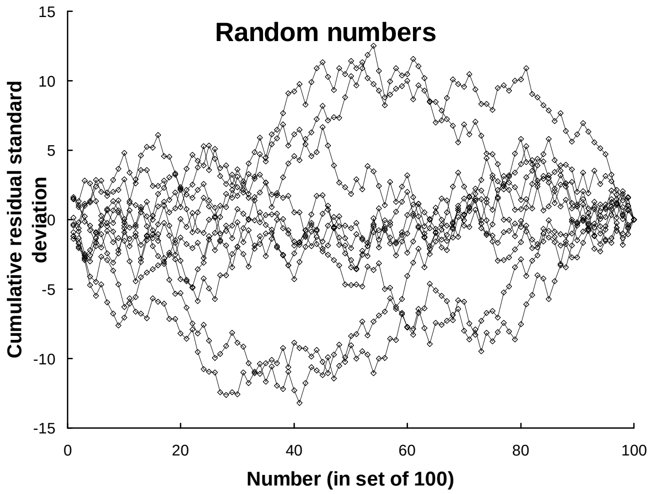

Figure 3. Cumulative residual standard deviations in ten sets of 100 random numbers.

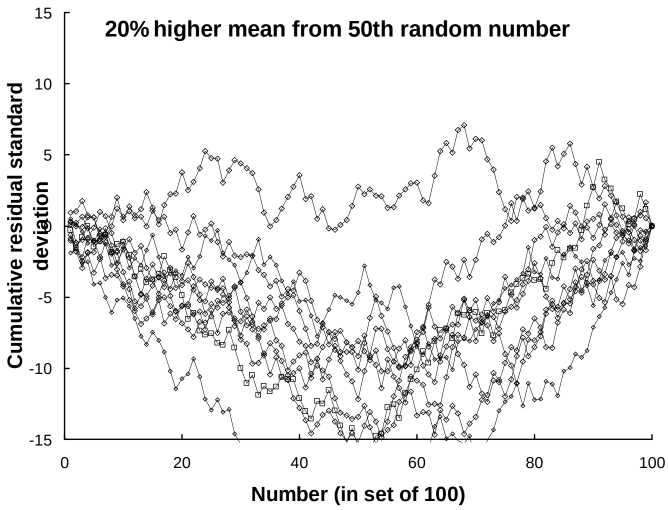

Figure 4. Cumulative residual standard deviations in ten sets of 100 random numbers, where the mean increases by 20% from the 50th number.

3. RESULTS AND DISCUSSION

3.1. Annual rainfall

The frequency distributions of annual rainfall amounts for the three sites are shown in Figure 5. They have a strong central tendency and relative to the normal distribution have only a mild bias towards values below the mean and away from values above the mean. Therefore, they are suitable for analysis using CRSDs. The CRSDs for the three sites have minima in the mid to early part of last century (Figure 6). For Moree and Wagga Wagga the minima are in the mid 1940s, a time that is widely considered a point of secular change in climate, including an increase in rainfall (Russell 1980), changes in floods and river channels (Erskine and Bell 1982) and changes in winds and sand movement (Ward and Russell 1980).

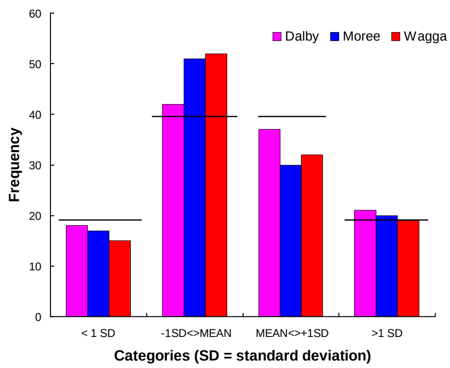

Figure 5. Frequency distributions of annual rainfall. The horizontal lines are for a normal distribution.

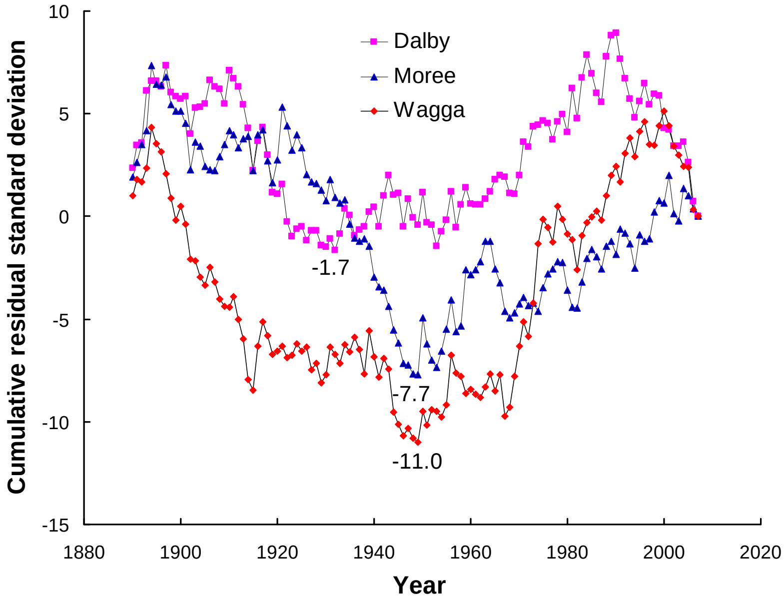

Figure 6. CRSDs for annual rainfall. Minimum CRSDs are shown for each site.

What was less expected was that the minimum for Dalby would be in 1932 (with low values from 1923 to 1932). The reason why Dalby did not experience the change in 1945 (known colloquially as the "Hiroshima effect") is not understood.

3.2. Deep drainage – wheat cropping

Table 1 shows the average annual deep drainage with wheat cropping at the three locations and the four soils. The high rates of deep drainage for the Kandosol are a feature. Although the PAWC of this soil (95 mm) is only moderately lower (approximately 25%) than for the Chromosol (134 mm) and the Dermosol (143 mm), the rates of deep drainage are more than doubled.

Table **1**. Average annual deep drainage (mm/year) of wheat crops.

	Site		
Soil type (Isbell 1996)	Wagga Wagga	Moree	Dalby
Kandosol	77	65	91
Chromosol	35	24	41
Dermosol	34	21	38
Vertosol	17	13	27

The relationships between annual rainfall (mm) and deep drainage (mm) for the two most contrasting soils at Wagga Wagga are shown in Figure 7. For the Kandosol, many years exceeding 400 mm of rainfall have deep drainage, and years above 800 mm generally have more than 100 mm of deep drainage. The Vertosol, however, provides a significant buffer against deep drainage, with mostly zero values for annual rainfall less than 800 mm.

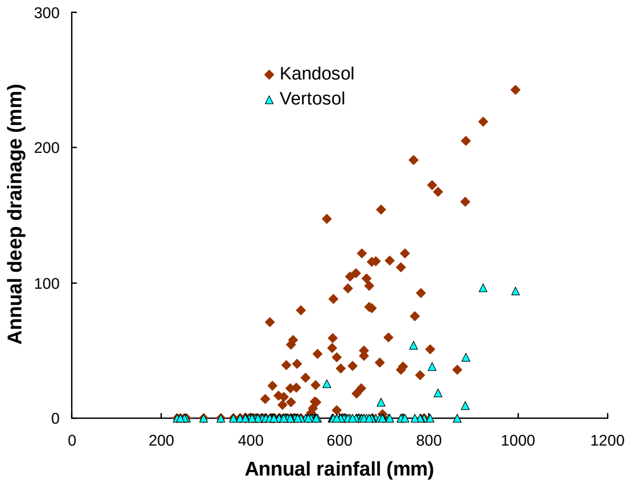

Figure 7. Annual rainfall and annual deep drainage at Wagga Wagga for wheat cropping and either a Kandosol (95 mm PAWC) or a Vertosol (198 mm PAWC).

Like annual rainfall, the annual deep drainage data were near-normal (results not shown), making interpretation of CRSDs simple. The CRSDs for the three sites and wheat cropping on the Kandosol are shown in Figure 8. Given the correlation between annual rainfall and annual deep drainage (Figure 7), it is not surprising that the overall patterns of CRSDs are somewhat similar. The CRSDs for Dalby have at least two interesting features. Firstly, they reach a much lower minimum than the CRSDs for rainfall (-4.8 *vs* -1.7) and the period 1930 to 1960 has falling values rather than rising values. Therefore deep drainage was below average while rainfall was above average. This may have been due to several factors, including changes in evaporation, planting time (which depends on the timing of rainfall), or the seasonality or daily amounts of rainfall. At Moree the minimum of the CRSDs for deep drainage occurs at more or less the same time as for rainfall (1949 and 1948, respectively). However, the CRSDs for deep drainage returned to a near-minimum in 1981 (blue circle), while rainfall did not return to its previous lows. At Wagga Wagga the CRSDs include extremely long sequences of near and below the mean (e.g. 1894 to 1915, red circles on left hand side), and near and above the mean (e.g. 1972 to 2000, red circles on right hand side). The likelihood of such long sequences occurring randomly in this climate record are low (compare Figures 7 and 2). That the minimum is less than that for rainfall (-14.2 vs -11.0) indicates that other factors had an additive effect with rainfall on deep drainage.

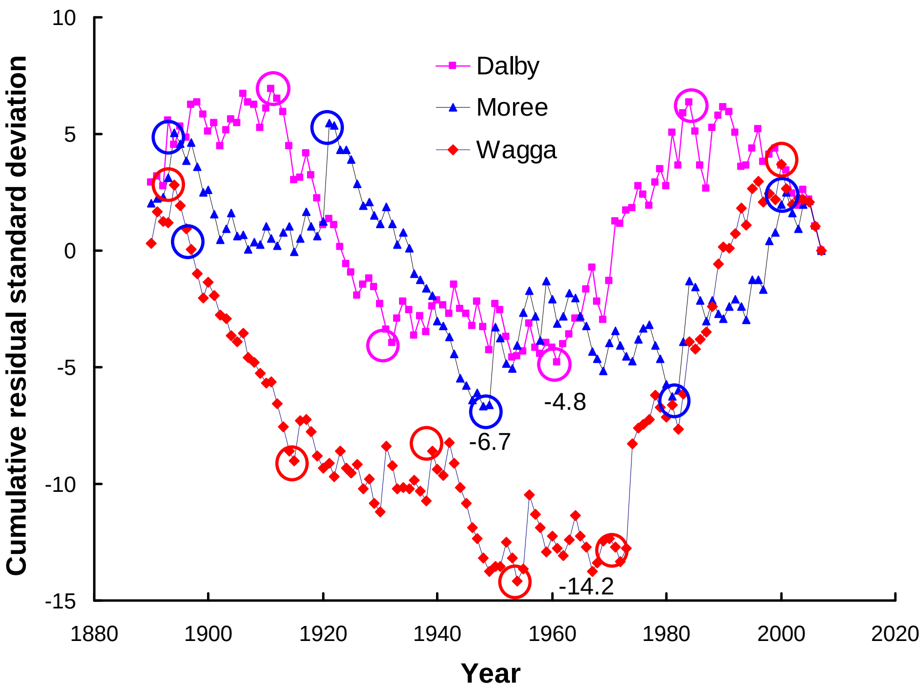

Figure 8. CRSDs for deep drainage with wheat cropping. Minimum CRSDs are shown for each site.

3.3. Deep drainage – native vegetation

Average annual deep drainage for the three sites and four soil types are shown in Table 2. The values are much lower than for wheat cropping (comparing Table 2 with Table 1). No CRSDs are plotted for these data because they are strongly skewed to low values, only containing between 1 and 39% of values above the mean (for the Vertosol at Dalby and the Kandosol at Wagga Wagga, respectively). The CRSDs are mainly long declining sequences (at the rate of the mean per year), interspersed with occasional large positive residuals.

Table 2. Average annual deep drainage (mm/year) of native vegetation.

	Site		
Soil type (Isbell 1996)	Wagga Wagga	Moree	Dalby
Kandosol	39	10	14
Chromosol	11	0.8	0.4
Dermosol	14	1.2	1.1
Vertosol	3.3	0.2	0.1

3.4. Climate predictors and indices

The graph of CRSDs for the SOI (Figure 9) has some turning points and trajectories that correspond to those of rainfall and deep drainage. Note that the amplitude of the CRSDs is not important, as climate is highly unlikely to be equally sensitive to departures from the means of the different indices. Points 1, 2 and 9 appear relevant, especially for Dalby, where the SOI is considered important for climate (Stone et al. 1996).

However, the minimum, at point 4, is earlier than the minima at any of the sites for rainfall or deep drainage. The negative of the Pacific Decadal Oscillation (-PDO) has a minimum (point 6) that coincides well with minima of the climate CRSDs, and a maximum (point 8) that precedes the maxima at Dalby by 5 to 10 years.

These climate indices are the result of more fundamental physical processes that drive climate. Some of these processes are changing or cyclical, and include solar output, volcanic activity, emissions of atmospheric aerosols, and emissions of greenhouse gases. The existence of associations between these processes and the water balance and crop yields have long been the subject of investigation and speculation (e.g. Gilliland 1982, Hammer et al. 1987). Changes shown here (Figure 8) were not simple, regular, or consistent across south east Australia. It would be surprising if only one or two climate forcing factors were responsible.

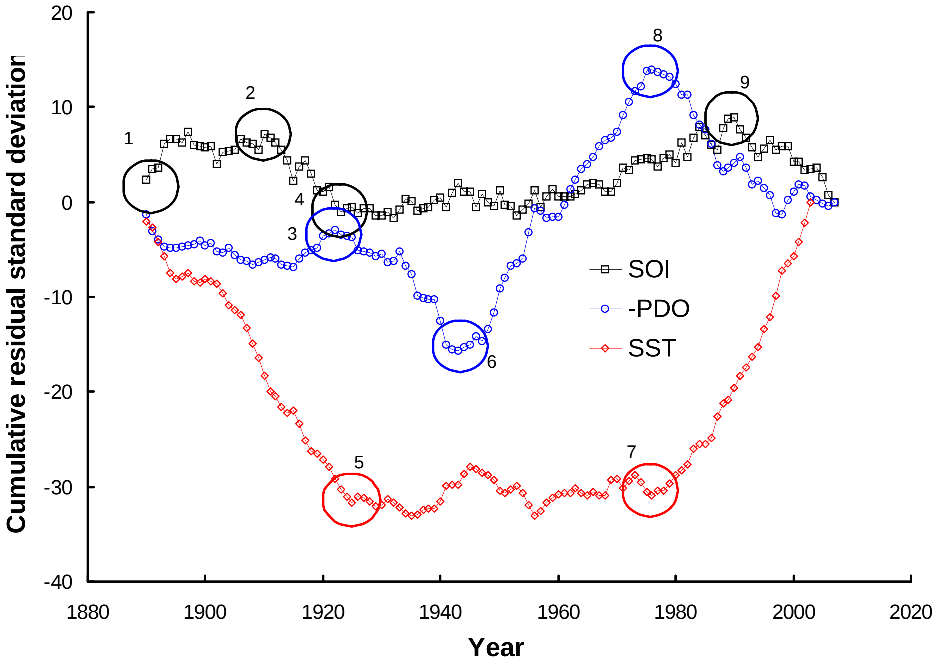

Figure 9. CRSDs for a range of climate indices. The southern Oscillation Index (SOI), negative Pacific Decadal Oscillation (-PDO) and tropical sea surface temperatures (SST) are shown.

4. CONCLUSIONS

4.1. Effects of location

There were large differences between locations for deep drainage under native vegetation (Tabe 2), and smaller differences for wheat cropping (Table 1). Except for the Kandosol soil type, native vegetation had virtually no deep drainage at Moree and Dalby. This is consistent with studies of solute movement in these systems (French et al. 2003).

4.2. Effects of soil type

As expected, soil type had a major effect on deep drainage (Table 1 and Table 2). The Kandosol with low PAWC (95 mm) had much higher rates of deep drainage than the Vertosol with high PAWC (198 mm).

4.3. Effects of vegetation type

Vegetation type had a major effect on deep drainage at every site and on every soil type (comparing Table 1 with Table 2). It is not surprising that clearing native vegetation for cropping is seen as the principle cause of dryland salinity. Further, shifting from crop-fallow land use to systems based on perennial species (such as perennial pastures) is likely to mimic the high transpiration and low deep drainage hydrology of the pre-European landscape (Ridley and Pannell 2005). In the northern grainbelt, Silburn et al. (2007) assessed the conversion of crop land to perennial pastures, and concluded it is an effective method reducing deep drainage and dryland salinity.

4.4. Possible cycles and changes in climate

The climate indices studied here, such as the SOI, are indirect measures of variations in fundamental physical processes that drive climate. The physical processes include solar output, volcanic activity, emissions of atmospheric aerosols, and emissions of greenhouse gases, all of which have changed on decadal timescales over the period of study (WDC for Paleoclimatology 2009). The existence of associations between these processes and climate, the water balance and crop yields in Australia has long been the subject of investigation and speculation (e.g. Gilliland 1982, Hammer et al. 1987). The results here do not exclude the proposition that cycles and changes have occurred. The evidence against cycles and changes was particularly weak for Wagga Wagga, where rainfall and deep drainage were serially lower than the long-term mean from just before 1900 until almost 1920, and again in the 1940s. A very long series of years above the mean occurred from approximately 1970 to 2000. Moree and Dalby also had series of years that are reasonably difficult (but not impossible, of course) to explain in terms of normal, stable distributions of rainfall and deep drainage. Recently, each site has had a series of falling CRSDs for rainfall and deep drainage which corresponds to a reduction in the extent of deep drainage in some areas. However, this recent trend in climate should not be taken as an indication of future climate, as some sequences of low and high rainfall and deep drainage have lasted no longer than the current episode.

ACKNOWLEDGMENTS

The author is funded by the Cotton Catchment Communities Cooperative Research Centre via project 2.01.02. Don Gaydon and an anonymous referee offered helpful advice with the manuscript.

REFERENCES

Abbs, K. and Littleboy, M. (1998), Recharge estimation for the Liverpool Plains. *Australian Journal of Soil Research,* 36, 335-357.

Erskine, W. and Bell, F.C. (1982), Rainfall, floods and river channel changes in the upper Hunter. *Australian Geographical Studies*, 20, 183-196.

French, V., Whish, J., Tolmie, P., Cook, R. and Egan, P. (2003), Understanding deep drainage in Grey Vertosols of the Moonie and Condamine catchments of south east Queensland, Proceedings of 13th Agronomy Conference. Perth, September 2006.

Gilliland, R.L. (1982), Solar, volcanic, and CO2 forcing of recent climatic changes, *Climatic Change*, 4, 111-131.

Greiner, R. (1998), Catchment management for dryland salinity control: Model analysis for the Liverpool Plains in New South Wales, *Agricultural Systems,* 56, 225-251.

Hammer, G.L., Woodruff, D.R. and Robinson, J.B. (1987), Effects of climatic variability and possible climatic change on reliability of wheat cropping – a modeling approach, *Agricultural and Forest Meteorology,* 41, 123-142.

Isbell, R.F. (1996), The Australian soil classification. CSIRO Publishing, Melbourne.

Littleboy, M., Freebairn, D.M., Silburn, D.M., Woodruff, D.R. and Hammer, G.L. (1999), PERFECT Version 3.0. A computer simulation model of productivity erosion runoff functions to evaluate conservation techniques, available at http://www.apsru.gov.au/apsru/Products/Perfect/PERFECT.HTM

Rattray, D.J., Freebairn, D.M., McClymont, D., Silburn, D.M., Owens, J. and Robinson, J.B. (2004), HOWLEAKY? - the journey to demystifying simple technology, paper presented at Conserving Soil and Water for Society: Sharing Solutions, the 13th International Soil Conservation Organisation Conference. Brisbane, July 2004.

Ridley, A.M. and Pannell, D.J. (2005), The role of plants and plant-based research and development in managing dryland salinity in Australia, *Australian Journal of Experimental Agriculture*, 45, 1341-1355.

Russell, J.S. (1981), Geographic variation in seasonal rainfall in Australia – an analysis of the 80-year period 1895-1974, *Journal of the Australian Institute of Agricultural Science*, 47, 59-66.

Silburn, D.M., Robinson, J.B. and Freebairn, D.M. (2007), Why restore marginal cropland to permanent pasture? - land resource and environmental issues, *Tropical Grasslands*, 41, 139-153.

Stone, R. and Auliciems, A. (1992), SOI phase relationships with rainfall in eastern Australia, *International Journal of Climate,* 12, 625-636.

Stone, R.C., Nicholls, N., and Hammer, G.L. (1996), Frost in NE Australia: Trends and influences of the Southern Oscillation Index, *Journal of Climate*, 9, 1896-1909.

Ward, W.T. and Russell, J.S. (1980), Winds in southeast Queensland and rain in Australia and their possible long-term relationship with sunspot number, *Climatic Change*, 3, 89-104.

WDC for Paleoclimatology (2009), World Data Center for Paleoclimatology - Data Sets Listing, http://www.ncdc.noaa.gov/paleo/datalist.html, accessed 31/3/2009.