Towards quantifying shallow groundwater-climate relationships in central and northern Victoria

Gavin M. Mudd[#], Sasha Jelecic, Felicity Ginnivan
[#]Lecturer, Institute for Sustainable Water Resources / Dept. of Civil Engineering, Monash University, Clayton, VIC, Australia
[#]E-mail: Gavin.Mudd@eng.monash.edu.au

Mark Reid
Primary Industries Research Victoria (VDPI), Epsom, VIC, Australia
E-mail: Mark.Reid@dpi.vic.gov.au

ABSTRACT: A vital aspect of managing and mitigating against dryland or irrigation salinity is understanding the water balance of a particular region. In particular, it is necessary to quantify the magnitude of groundwater recharge that can occur as a result of rainfall events of varying magnitude and intensity. This information can then be used to improve understanding of the hydrologic controls in a given area, and therefore inform land management decisions with respect to salinity processes. In this preliminary study, we present the results of relationships between rainfall, evaporation and rises/falls in the water table for the Black Ranges in central Victoria and Woorinen Lakes area of northern Victoria. Data was obtained on groundwater levels from numerous bores at each site, combined with 25 years of climate data on rainfall and evaporation from the nearest station available. The methodology involved examining individual periods of rise and fall in groundwater and estimating cumulative rainfall, evaporation and net hydrologic flux. These data points were graphed for several bores to establish potential relationships. The results show that there are variable correlations, ranging from low to high R^2 values (ie. 25% to 85%), with common R^2 values around 50-60%. The results demonstrate, cautiously, that rises and falls in the water table can be attributed to climatic forcing conditions (ie. rainfall, evaporation), but they also suggest that understanding bore-specific issues are also important, including location in the hydrogeologic flow path, the thickness of the unsaturated zone and land use. This paper presents some useful results which can be used more broadly in understanding the links between groundwater and climatic conditions with respect to salinity and land management. This becomes especially important in the light of potential climate change impacts.

INTRODUCTION

The links between shallow groundwater resources and climate are subtle but critically important. Historically, the significance of these relationships have not been fully appreciated, in turn contributing to the challenges we currently face with salinity and land management.

In this paper, we present a preliminary study analysing two sites in Victoria, firstly at Black Ranges near Dunolly in central Victoria and secondly at the Woorinen Lakes District in northern Victoria. Long-term groundwater and climatic data is presented and analysed, seeking to establish possible relationships.

BACKGROUND AND SITE DESCRIPTIONS

The challenges of salinity and potential climate change impacts are leading to major shifts in thinking in the use and management of land across Australia. To inform this shift, it is imperative to understand the hydrologic controls in a given region, especially the links between rainfall, evaporation and the response of shallow groundwater (or water table). A preliminary study was undertaken at two sites in Victoria to determine if useful relationships could be established between rainfall events of various size and the corresponding rise in the water table. In addition, the influence of evaporation was investigated as well as ‘net hydrologic flux’.

Figure 1 Location – Black Ranges and Woorinen Lakes District, Victoria

Black Ranges, Central Victoria

The Black Ranges is located west of Bendigo (Figure 1), ~15 km south-west of Dunolly, in the Bet Bet catchment. The Black Ranges itself are composed of granite, metamorphic schists, gneiss and quartzites (Day, 1985). Soils are generally thin and coarse or absent on the slopes, while alluvial terraces can contain clayey soils, sands and/or siliceous hardpans.

The principal land use is dryland agriculture, mainly sheep grazing. Typical climate consists of hot dry summers with mild wet winters. Average annual rainfall is ~505 mm, falling commonly in winter, while average annual pan evaporation is ~1,390 mm (BoM, 2006).

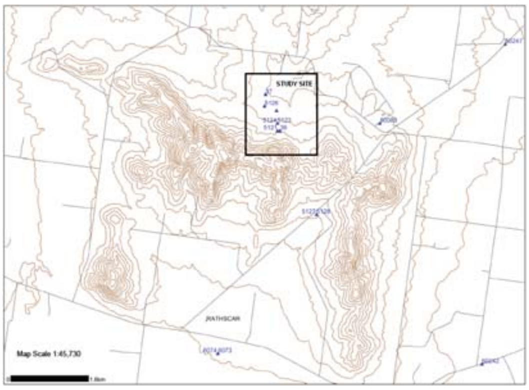

Figure 2 Black Ranges contours and groundwater bores (DSE Interactive Maps www.dse.vic.gov.au)

Salinity occurs along the northern slope of the Black Ranges. A number of groundwater bores are located in this region, Figure 2, and have been regularly monitored for about 20 years.

Woorinen Lakes, Northern Victoria

The Woorinen Lakes Irrigation District (WLID) is north-west of Swan Hill (Figure 1). The soils are generally sandy, often calcareous and fine-grained, belonging to the Shepparton Formation.

The region supports irrigation horticulture and in recent years has seen a major upgrade to water delivery infrastructure. Historically irrigation was supplied through gravity-based open channels. In 2002 the channels were replaced by pipes to improve water efficiency.

The climate is similar to the Black Ranges. Average annual rainfall is ~335 mm, falling commonly in winter, while average annual pan evaporation is ~1,725 mm (BoM, 2006). The surface topography is extremely flat.

METHODOLOGY

Data Sources - Groundwater

The Black Ranges groundwater data was obtained for 10 bores from 1986 to 2005 from the Victorian Department of Primary Industries, based on long-term monitoring by local land users (Figure 2). This includes some nested bores, monitoring both the upper and lower water tables (left as independent series to establish any effects). The Woorinen Lakes district groundwater data for 15 bores from 1985 to 2005 was provided courtesy of Sinclair Knight Mertz Pty Ltd (SKM), based on their ongoing investigations in the region, shown in Figure 3.

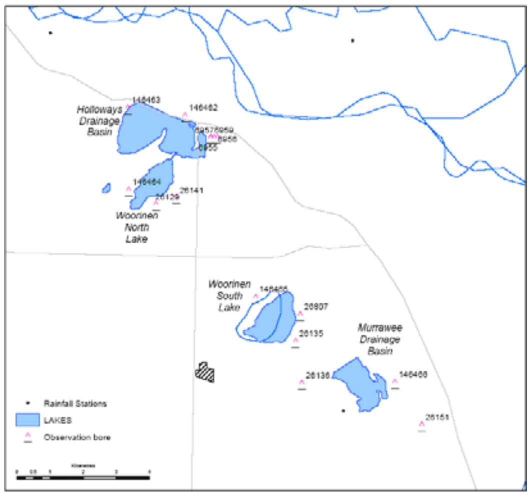

Figure 3 Location – Black Ranges and Woorinen Lakes District, Victoria (courtesy SKM)

Data Sources - Climate

The climate data, rainfall and pan evaporation, was obtained from the SILO Data Drill service (operated by Queensland Department of Natural Resources and Mines, QNRM) (see Jeffrey et al. 2001). Although this data is interpolated, it is considered sufficient to undertake a preliminary analysis of trends and relationships before proceeding to more rigorous methods.

Analysis Techniques

The groundwater and climate data was analysed using the approaches outlined by Armstrong & Narayan (1998). In brief, the magnitudes of rises and falls in the groundwater table were plotted against cumulative rainfall, evaporation or 'net hydrologic flux' (rainfall minus evapo-transpiration). All events were analysed for each bore, as shown in Figure 4. As the water tables are relatively shallow at both sites, the hydrologic regime can be simplified as a vertical system with no significant delay or lag.

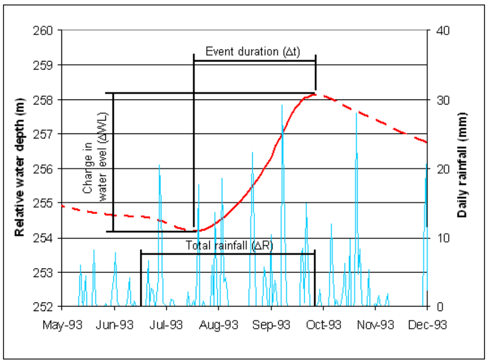

Figure 4 Typical analysis of groundwater rise and cumulative rainfall

RESULTS

The groundwater data for the Black Ranges is shown in Figure 5 and groundwater and rainfall data for the Woorinen Lakes district in Figure 6. Both figures demonstrate the variable nature of the water tables for each region. In particular, a general trend of declining levels is evident over the past several years due to the drought.

For the Black Ranges, groundwater rise versus cumulative rainfall is shown in Figure 7, groundwater fall versus cumulative evapo-transpiration in Figure 8 and groundwater change versus net hydrologic flux in Figure 9. The full graphs are included for completeness (despite space constraints). Evapotranspiration is estimated as 0.7 of pan evaporation.

For the WLID, groundwater rise versus cumulative rainfall is shown in Figure 10 and groundwater fall versus cumulative evaporation in Figure 11 (both as full graphs). Groundwater change versus net hydrologic flux was analysed but mostly gave very poor correlations. Due to the lack of sufficient data, no irrigation could be included in the analyses of the WLID. Further analysis of the WLID is complicated by the recent introduction of piping into the region.

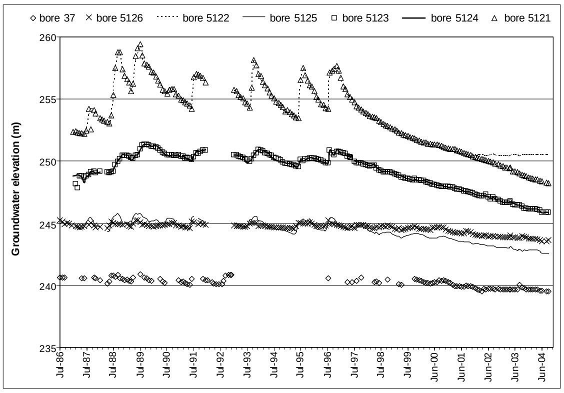

Figure 5 Groundwater elevations over time, Black Ranges

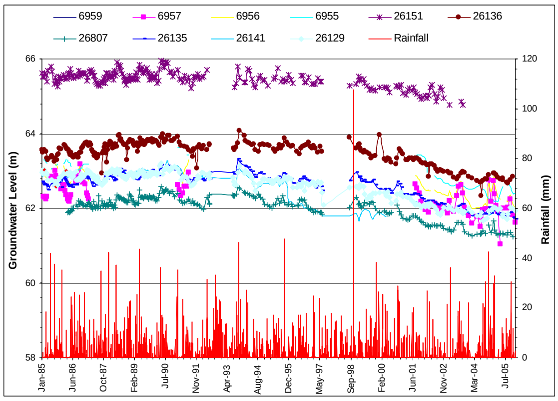

Figure 6 Groundwater elevations and rainfall over time, Woorinen Lakes Irrigation District

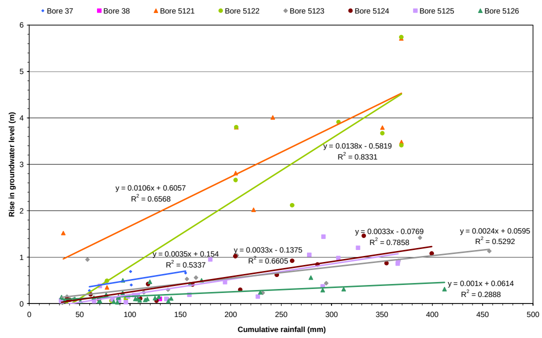

Figure 7 Groundwater rise versus cumulative rainfall, Black Ranges

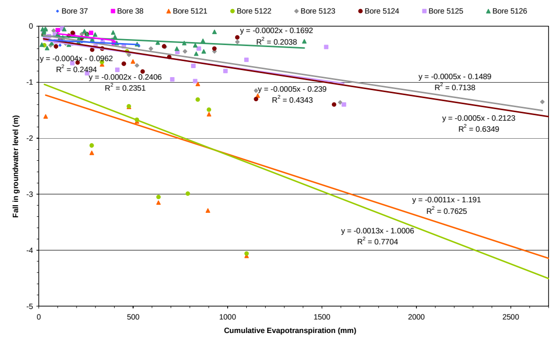

Figure 8 Groundwater fall versus cumulative evapotranspiration, Black Ranges

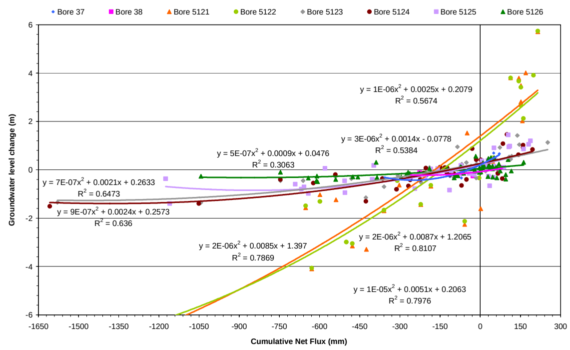

Figure 9 Groundwater change versus net hydrologic flux, Black Ranges

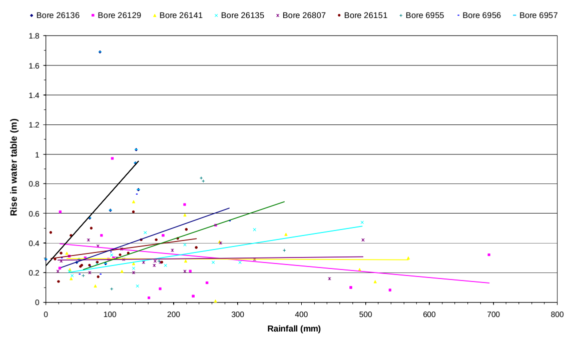

Figure 10 Groundwater rise versus cumulative rainfall, Woorinen Lakes Irrigation District

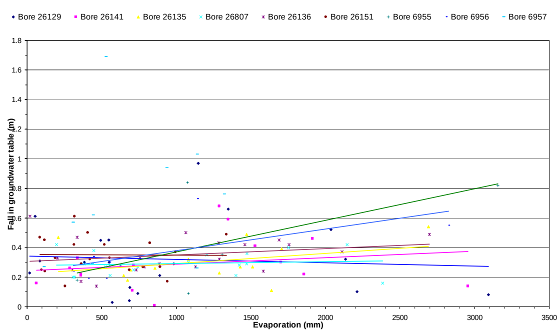

Figure 11 Groundwater fall versus cumulative evaporation, Woorinen Lakes Irrigation District

A summary of the R^2 coefficients for the various bores is compiled in Table 1. All values are based on linear regressions, except for groundwater change versus net flux for the Black Ranges which are based on second-order polynomial regressions (all calculated from within Microsoft Excel).

Table 1 R^2 values from statistical regressions

Woorinen Lakes	G-v-R	G-v-E	G-v-F
Bore 26136	25.2	6.1	-
Bore 26141	0.3	3.8	-
Bore 26807	0.8	1.1	-
Bore 26129	8.5	0.6	-
Bore 26151	12.2	0.2	-
Bore 6956	42.9	41.1	-
Bore 6957	25.2	6.1	-
Bore 6955	26.0	42.3	-

Black Ranges	G-v-R	G-v-E	G-v-F
Bore 37	53.4	23.5	79.8
Bore 38		24.9	53.8
Bore 5121	65.7	76.3	78.7
Bore 5122	83.3	77.0	81.1
Bore 5123	52.9	71.4	64.7
Bore 5124	78.6	63.5	63.6
Bore 5125	66.1	43.4	56.7
Bore 5126	28.9	20.4	30.6
Average	**61.3**	**50.1**	**63.6**

Note : G-v-R – groundwater rise versus rainfall; G-v-E – groundwater fall versus evaporation; G-V-G – groundwater change versus net hydrologic flux.

DISCUSSION

A number of issues need to be considered in the interpretation of this preliminary work. Firstly, the actual evapotranspiration is not monitored by climate stations. This can vary with soil and vegetation type, land use, salt content, topography and the like. For example, salt crusts can form and act to minimise evaporation from a soil profile. Secondly, the time scales of the various data are not co-incidental, as groundwater is commonly monitored monthly while climate is monitored daily and irrigation at the WLID is only reported annually. Although cumulative data can overcome this to a point, it still introduces a degree of uncertainty into the analysis. Thirdly, other aspects of the water cycle (or budget) in an area need to be assessed. At the Woorinen Lakes Irrigation District, the timing of water volumes for irrigation need to be incorporated, though this was not possible due to the lack of data at an appropriate temporal scale as climate and groundwater monitoring. The recent introduction of piping as well as the prolonged drought has meant that it is not possible to the degree of analyses for the WLID. These factors are probably the main causes of the poor correlations obtained between groundwater, rainfall and evaporation.

For the Black Ranges, the reasonable R^2 results obtained are probably related to the fact the site is simpler in its water balance than the WLID. However, the factors noted above still require further assessment.

Overall, the correlations range from poor (<40% R^2) to strong (>80% R^2). The correlations (R^2) for the Woorinen Lakes region are generally poor while those for Black Range are more variable but average 50-60% R^2. The average R^2 of 63.6% for groundwater change versus net hydrologic flux suggests that this is perhaps a more useful approach in accounting for the relationship between the water table and climate at a given site.

CONCLUSIONS

The historical links between shallow water tables and prevailing climatic conditions over the past twenty years has been investigated and preliminary analysed at the Black Ranges and Woorinen Lakes Irrigation District in Victoria. The simplified technique of plotting the rise or fall in the water table versus rainfall or evaporation, respectively, has proven useful at the Black Ranges but not for the WLID. This could be due to a range of site-specific factors as well as the lack of appropriate monitoring data for irrigation. To improve this analysis and obtain more comprehensive insights, future research is intended to apply more complex time series statistical techniques as well as linking (or eliminating) site-specific factors into the work.

ACKNOWLEDGMENTS

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