EXPLAINING GROUNDWATER DEPTHS IN SALTLAND: IMPACTS OF SALTBUSH, RAINFALL, AND TIME TRENDS

R. Ferdowsian[a]*, D.J. Pannell*[b] *and M. Lloyed*[c]
[a]*Department of Agriculture, Albany WA 6330, Australia (rferdowsian@agric.wa.gov.au)*
[b]*CRC for Plant-Based Management of Dryland, University of Western Australia, Crawley, WA 6009, Australia (david.pannell@uwa.edu.au)*
c Bundilla Farms, Lake Grace (lloyd.vs@farmwide.com.au)

ABSTRACT

Monitoring changes in groundwater levels is helpful to detect the effectiveness of the rehabilitation treatments. Many researchers have studied groundwater level changes and attempted to explain them statistically. The common statistical analysis do not explain the changes in groundwater levels very well if the watertable is close to the soil surface. We present an approach for statistically estimating changes in groundwater levels including the impacts of treatments on those levels. This approach explains the changes in groundwater levels very well. The approach not only separates the effect of rainfall events from any underlying time trend but it also estimates the impact of other factors, such as evaporation and saltbush on groundwater levels. Some examples of application of the approach are presented.

Keywords: Saltbush; Atriplex; Groundwater; Monitoring; Treatment; Salinity; Rehabilitation of saline land; Sustainability indicators

INTRODUCTION

By 1994, an estimated 1.8 million hectares of cleared land in Western Australia was affected by secondary dryland salinity to some extent, representing 9.4 percent of agricultural land in the state (Ferdowsian et al., 1996). This area is likely to double in the coming 20 years (to around 3.3 million ha) and may redouble again before a new equilibrium is reached. The salt-affected areas are usually the least productive part of the landscape. Many farmers have planted saltbush (*Atriplex* species to rehabilitate the saline land and change them to productive areas. Monitoring changes in groundwater levels is helpful to detect the effectiveness of these rehabilitation treatments.

Ferdowsian *et al.,* (2001) presented a new approach called HARTT (Hydrograph Analysis: Rainfall and Time Trends) for statistically estimating groundwater levels. Their method differentiates between the effect of rainfall fluctuations and the underlying trend of groundwater levels over time. Rainfall is represented as an accumulation of deviations from average rainfall and the lag between rainfall and its impact on groundwater is explicitly represented. The HARTT method provides high quality fits to observed data in all but shallow bores (Ferdowsian *et al.,* 2001), and even in these cases, the approach is superior to the time-trend-only approach.

The common statistical approach (and even the HARTT method) does not well explain the changes in groundwater levels under saltbush plantations. This is because groundwater levels under these areas are usually close to the soil surface and are affected by a diversity of factors such as rainfall, evaporation, vegetation, plant density, hydraulic gradient, hydraulic conductivity and depth to groundwater. We need a refined model for explaining changes in watertable under saltbush plantations.

The model presented here is a variation on the HARTT method, including the monthly rainfall with various delays. It relates the seasonal fluctuation in groundwater levels to variation in delayed monthly rainfall and variables representing the presence or absence of saltbush. In the following sections, we explain the approach and present five examples of its application when saltbush treatment has been implemented.

DATA AND SITE DETAILS

The Bundilla farm (118°48′E, 32°55′ S) is located 62 Km north east of Lake Grace in the wheat belt of Western Australia and in a 330 mm annual rainfall zone. The landscape consists of flats with level (<1%) plains and broad (between 1 to >3 Km wide), poorly defined stagnant sedimentary depressions. The broad depressions gradually change to stagnant broad flats with naturally saline areas and saline shallow playas. The upper parts of the broad depressions, which did not have primary salinity, have been cleared for agriculture. These areas have shallow (A horizon <0.25 m) duplex soils (Northcote, 1979). Excessive recharge due to common agricultural practices has caused the levels of very saline groundwater to rise and come close to soil surface (<1.0 m) resulting in expanding soil salinity. The aquifer is stagnant with level (<1%) hydraulic gradient and very little or no flow going out of the area. Consequently the groundwater levels have only one dimensional (up and down) movements.

The soils of the valley floor contain high levels of salt (Figure 1). At the soil surface, the salt storage is less than 5 kg m^{-3}, but it increases to greater than 15 kg m^{-3} below 2 metres depth.

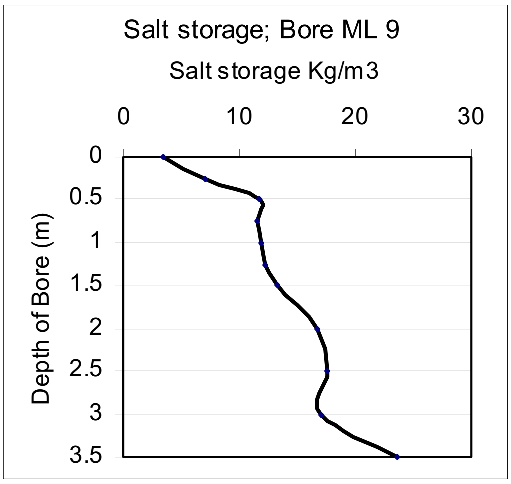

Figure 1: Salt storage increases with depth and large amount of salt is stored in the soil profile.

The farmer has planted large areas (hundreds of hectares) under saltbush to prevent soil salinity and change the area to productive land. The site is an important and a common place for Field Days and has attracted hundreds of farmers and researches to observe productivity of the site. More than 10 shallow bores (< 5 m) were drilled in the area in early 1994, to observe and record changes in groundwater levels and document the effect of saltbushes on watertable. The landholder has records of monthly rainfall and groundwater levels with only a few missing data in groundwater levels. The records are valuable data set for documenting the effectiveness of saltbush in soil salinity prevention. We have used the rainfall data and the records of 5 bores to document the changes in groundwater levels in various growth periods of saltbush.

The five selected bores were all drilled in early 1994 but saltbush planting and their present conditions varied (Table 1).

Table 1: The year and method of planting saltbush and their present conditions.

Bore No	Year of planting	Method of saltbush establishment	The present condition (Farmers assessment)
ML 1	1989	Seedlings	Average
ML 7	1997	Direct seeded	Stunted bushes
ML 8	1997	Direct seeded	Better than the previous case (Average)
ML 9	1999	Direct seeded	Good conditions
ML 10	1999	Direct seeded	Good conditions

ANALYTICAL METHOD

Watertable depth was hypothesised to depend on rainfall, time and saltbush according to the following functional relationship.

$$\text{Depth}_t = k_0 + k_1 \times R_{t-1} + k_2 \times R_{t-2} + k_3 \times R_{t-3} + k_4 \times R_{t-4} + k_5 \times t + k_6 \times S_t \quad (1)$$

t is time (in months) since the start of the data set.
k_0 is an intercept term. In models with no time trend, it is the base line water table depth that the model returns to after the effects of rainfall have passed.
R_{t-1} to R_{t-4} represent the rainfall in the months prior to taking the reading of water table depth.
S_t represents the number of months since establishment of saltbush.
k_0 to k_6 are parameters to be estimated by multiple regression.

In some cases, the S_t variable was separated into two variables, representing the first 30 months of saltbush establishment, and subsequent months of saltbush. This separation allowed us to test whether the influence of saltbush on watertable depth changed over time.

Regressions were undertaken using the Microsoft Excel software package. It would be possible to use a Tobit regression analysis to improve the estimation of data sets with dry readings, but that was not done in this study. Where estimated parameters failed a T test for difference from zero, they were dropped from the model and it was re-estimated.

RESULTS

The statistical analysis showed that despite having shallow groundwater levels, the explanatory power of the model was very good (Table 2). All parameters listed in Table 2 had significant ($P<0.02$) effect on groundwater levels. Between 68% and 84% of changes in groundwater levels in the 5 selected bores could be explained (Table 2). We consider these to be very good results in terms of statistical fit. In all cases monthly rainfall increased groundwater levels significantly and its effect lasted for 3 to 4 month after the event. To describe the effect of saltbush during its life cycle each bore will be reviewed separately.

Table 2: Statistical analysis results of the 5 selected bores in saltbush.

Bores	ML 9	ML 10	ML 7	ML 8	ML 1
Number of months under saltbush	32	32	56	56	all
R Square	0.683	0.716	0.746	0.805	0.837
Intercept	-1.659	-1.839	-1.409	-1.831	-1.738
Trend (m/year)	n.s.	n.s.	0.105	0.062	n.s.
Effect of monthly rain (1 month delay; m/mm)	0.006	0.004	0.009	0.008	0.010
Effect of monthly rain (2 month delay; m/mm)	0.005	0.006	0.004	0.007	0.005
Effect of monthly rain (3 month delay; m/mm)	0.006	0.004	0.003	0.004	0.003
Effect of monthly rain (4 month delay; m/mm)	n.s.	0.004	0.003	0.003	0.002
Effect of treatment (first 0-30 months; m/month)	-0.016	-0.031	-0.011	-0.020	Not detected
Effect of treatment (after 30 months; m/month)			00	-0.006	

Notes: Monitoring period has been since 1994.
n.s. is for parameters which, were not significant ($P>0.04$) and were removed from the model. All parameters included in the table were significant with P values <0.02.

Bore ML9

Bore ML9 was under saltbush for only 32 months and was in a location where saltbush plants were relatively sparse. The model explained 68% of the variation in watertable depth, despite having a few "dry" records where the watertable was below the depth of the bore (Figure 2).

There was no underlying time trend for groundwater level prior to planting saltbush. The watertable fluctuated above a –1.66 m baseline, with depth at any point in time depending on rainfall over the previous three months. Table 2 shows that for three of the five bores, the influence of rainfall on watertable depth was greatest for the most recent rainfall and progressively smaller for rainfall in the more distant past. Bore ML 9 was an exception to this; its parameters for monthly rainfall were similar for the three most recent months.

Saltbush caused a significant reduction (-0.016 m/month; 0.19 m/year) in groundwater level during its 32-month period of effect. The thin line to the right of September 1999 shows the result of using the estimated statistical model to predict what the groundwater depth would have been during this period if saltbush had not been established. By the end of the 32-month period, the total effect of the saltbush on groundwater level was estimated to be 0.5 m. In view of the relative sparseness of saltbush at this location, such a fall in level is encouraging. Given that the data set includes a large number of "dry" readings, the true impact on groundwater is likely to have been greater than the 0.5 m estimated.

Bore ML10

Like bore ML9, bore ML10 was under saltbush for only 32 months and often during this period the watertable dropped below the drilling depth (Figure 3). The model explained 72% of the variation in watertable depth, as a function of rainfall and the presence of saltbush. Like bore ML9, the estimated influence of rainfall did not decline greatly with time (Table 2), extending to four months in this case. There was again no underlying time trend for groundwater level prior to planting saltbush. Watertable dropped by -0.031 m/month (0.37 m/year) during the period of saltbush, around twice the estimated rate for bore ML9.

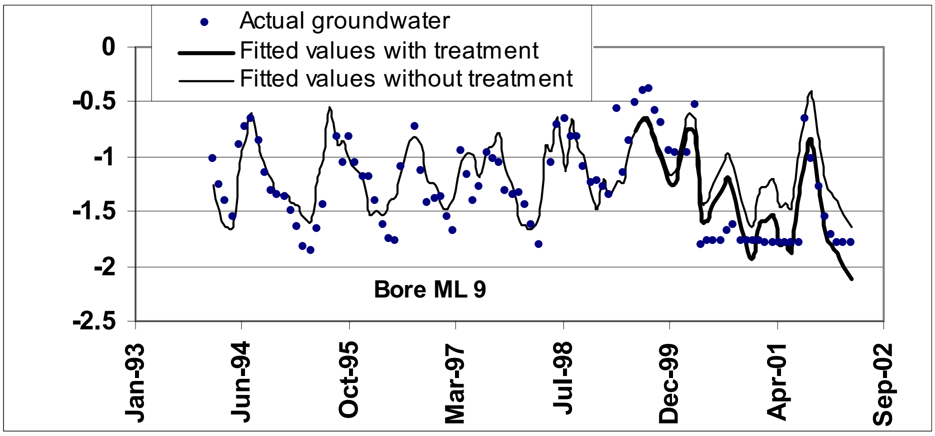

Figure 2: Hydrograph for bore ML 9 showing the net effect of saltbush on groundwater levels. (Final effect was a drop of 0.5m). During a number of months groundwater dropped below the bore's maximum depth of 1.8m.

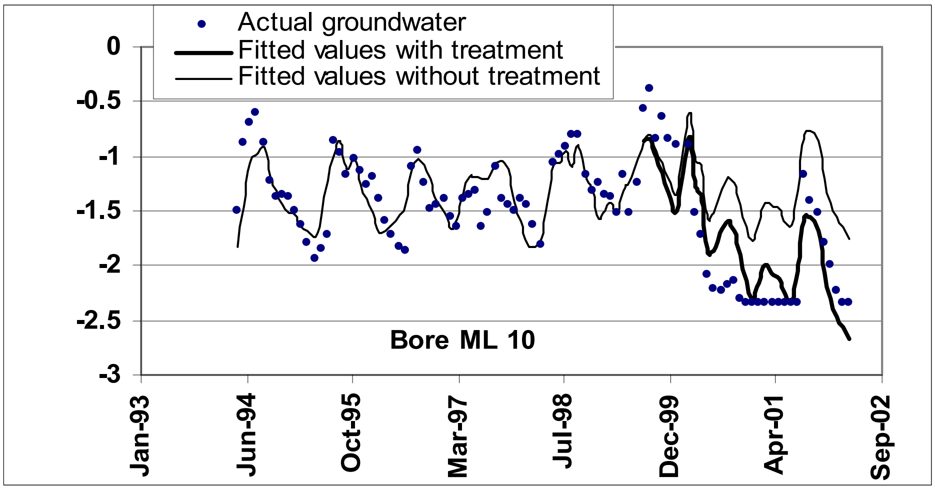

Figure 3: Hydrograph for bore ML 10 showing the net effect of saltbush on groundwater levels. (Final effect was a drop of 0.9m). During a number of months groundwater dropped below the bore's maximum depth of 2.34m.

Bore ML7

Results for bore ML 7 are shown in Figure 4. This bore had 39 months monitoring prior to and 54 months after saltbush was planted. Further, its watertable fell to the bore depth on only a few occasions, so that a higher quality estimate of the impact of saltbush was possible than for the previous two bores.

Prior to planting saltbush there was an underlying time trend of 0.105 m rise per year in the groundwater level. For around 30 months after the establishment of saltbush, the estimated trend reversed and fell at 0.13 m per year. After that, it appears that the groundwater trend stabilised, with rainfall causing rises above a constant base depth of 1.4 m. Thus, in this case, the saltbush was able to prevent groundwater from rising to near the soil surface, but it was not able to lower the watertable below a depth of 1.4 m.

The thin line to the right of September 1997 shows the predicted watertable depth in the absence of saltbush. According to the model, groundwater would have been discharging at the surface for two periods. Note that the predicted depths for the without-saltbush case do not take account of the loss of water from these periods of discharge.

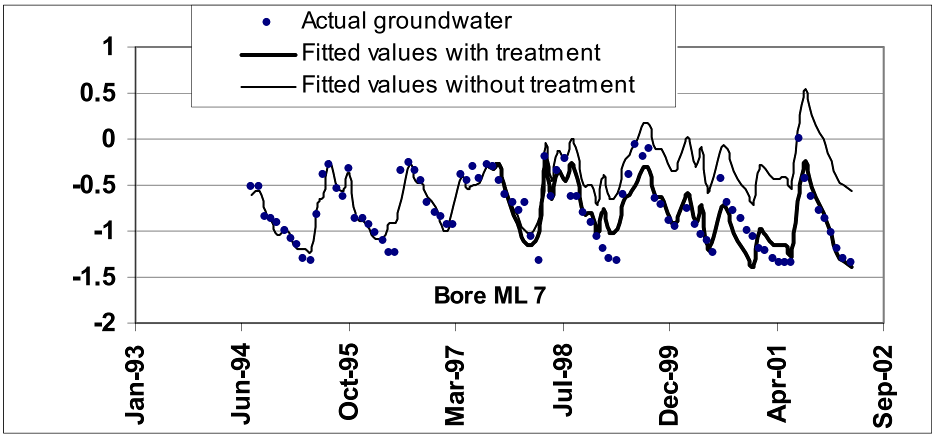

Figure 4: Hydrograph for bore ML 7 showing the net effect of saltbush on groundwater levels. (Final effect was a drop of 0.8m).

Bore ML 8

Results for this bore (Figure 5) were somewhat similar to bore ML 7, albeit with slightly deeper watertable depths. There was 0.06 m/year rising trend prior to saltbush establishment, and a falling trend of 0.24 m/year during the first 30 months of saltbush. As with Bore ML 7, the rate of groundwater level reduction by saltbush was not sustained; it fell to 0.07 m/year after 30 months. The predicted water table depths in the absence of saltbush were around 0.9 m shallower by the end of the observation period.

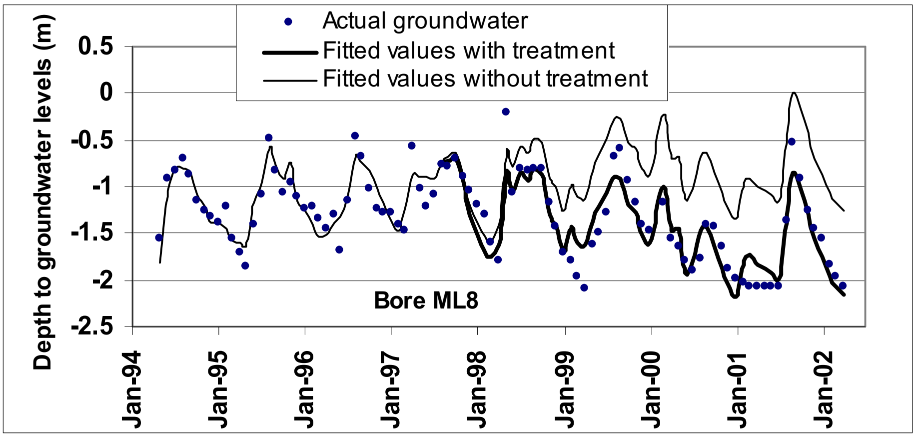

Figure 5: Hydrograph for bore ML 8 showing the net effect of saltbush on groundwater levels. (Final effect was a drop of 0.9m). During a number of months groundwater dropped below the bore's maximum depth of 2.08m.

Bore ML1

Bore ML1 was drilled after saltbush had already been established. Therefore we were unable to detect the effect of saltbush. However we can observe that the system stayed in equilibrium during the monitoring period (1994 to 2002) and there was no underlying time-related trend in groundwater levels (Figure 6). Fluctuations in groundwater level were temporary effects of local rainfall. After each period of rainfall, the watertable dropped towards the estimated base level of 1.74 m.

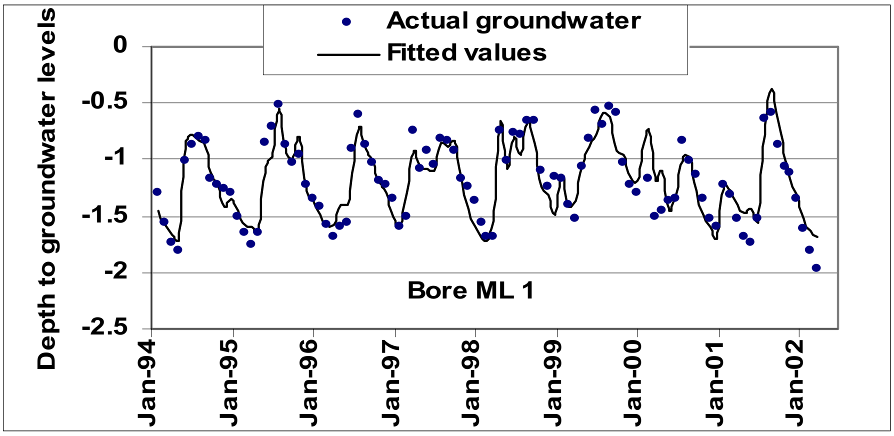

Figure 6: Hydrograph for bore ML 1 showing only seasonal fluctuation above the base line (-1.74 m).

CONCLUSION AND DISCUSSION

We have presented an approach to statistical modeling of hydrographs that appears to have some considerable strength. The method is simple to apply with standard regression methods. It provided high quality fits to observed data even when groundwater levels are close to the soil surface. It allowed the separation of the impacts of atypical rainfall events from any underlying time trend (if present) and quantified the effects of treatment very well. Results are highly consistent with hydrological expectations. In case studies, we have been able to discern the impacts of treatments on the groundwater rise and predict what the groundwater would have done in the absence of saltbush.

As expected, in the environment of the study area (shallow watertable, very low or no hydraulic gradient), groundwater levels have strong seasonal fluctuations due to local rainfall. The seasonality in groundwater levels could be significantly explained by monthly rainfall over the preceding four months. In two of the five case studies there was a slight rising trend in groundwater level prior to the establishment of saltbush, while in the other three, the long-term trend was flat.

The analysis show that saltbush can lower groundwater levels to below the capillary fringe and thus prevent ongoing worsening of soil salinity at the surface. Judging from the two bores that had been established for 56 months, this effect of saltbush on watertable effect was mostly completed within 30 months after planting. After that period, saltbush managed to keep groundwater levels at bay and prevent them from rising again.

There are impediments preventing saltbush from further lowering the watertable. Groundwater salinity (27,000 mg/L) and high salt storage (i.e. >15 Kg/m^3) are likely to be prominent amongst these limiting factors. The same factors may have affected the natural vegetation prior to clearing. In these cases the saltbush plantations may have reverted the hydrological processes back to preclearing conditions.

Under the environment of these case studies, rainfall adds water to the profile and the saltbush depletes it during the following four months. It appears that the saltbush is not drawing on the highly saline groundwater below depths of 1.5 to 2 m. These conclusions have important implications:

- In this dry environment (330 mm annual rainfall) saltbush will run short of water in dry seasons and its productivity may be affected by lack of water.
- Saltbush may perform better and be more productive, in areas with higher rainfall and lower salt storage.

In many areas increased concentration of chloride beneath stands of saltbushes can become a problem (i.e. Barrectt-Lennard and Malcolm, 1999). However, in the environment studied here, the production system appears to be sustainable, subject to survival of the saltbush plants. Because this part of the landscape has a one-dimensional groundwater flow system (i.e. movement is predominantly up and down, not to the side) salt buildup in the root zone of the saltbush plants will be prevented. This may not be the case where saline groundwater from another area flows to the root zone and replaces the depleted watertable.

ACKNOWLEDGEMENTS

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