

WET ROOTS?

GROUNDWATER AND SALINITY

MAPPING IN THE BOURKE IRRIGATION DISTRICT

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Introduction

Groundwater, under the right conditions can be of benefit to plants. For example, cotton can derive substantial water from groundwater at depths of around 2.6 m (Wallender et al. 1979). Excessive exposure to groundwater however can be detrimental. It has been shown that yield can be reduced by as much as 60% in the presence of a groundwater that rises from around 3 m to less than 1 m (Kahlowan and Azam 2002). This occurs by either a) extending the period for which the crop root zone is saturated after irrigation or b) soil remains permanently saturated in the root zone. The depth to groundwater is primarily a function of the environmental and geological setting in which the area is located. However land management practices also have varying degrees of influence on groundwater depth.

A knowledge of where the groundwater sits within the soil is therefore crucial for irrigated crop production. Where the groundwater is also saline elevated groundwater levels may not only lead to reduced crop growth through water logging but may also affect the crop through salinity stress. With respect to legumes, wheat and cotton yield, decreases will start to be experienced as salinity levels rise above 2, 6 and 8dS/m, respectively (Maas 1990). Mapping the spatial extent of groundwater depth is therefore necessary in order to understand the cause and best management, particularly when elevated groundwater levels lead to the expression of soil salinisation. Piezometers and water and moisture monitoring devices can give accurate indications of groundwater height and can highlight areas that may be prone to water logging. The disadvantage of these however is that they only give a point reading which may not be representative of conditions over entire paddocks or farms.

In the Bourke Irrigation District shallow water tables and incipient traces of point source salinisation became evident in the early 1980's. It was thought that the main driver for this was the presence of saline subsurface material at depths of 6-12 m. What were not known were a) the spatial extent of this material and b) the dynamics of the elevated groundwater levels that mobilizes the material into the rootzone.

The aims of this work are twofold, firstly to map with a high degree of accuracy the groundwater depth using remotely sensed and ground-based data at 100 m resolution, and secondly to map the subsurface salts that are present within the soil profile using electromagnetic techniques.

Materials and Methods

Study area

The study area covers approximately 300km² of irrigated and dryland country to the north of the Darling River. Figure 2 shows a Landsat image of the BID. The darker shaded areas are sandier and elevated parts of the landscape derived from Aeolian deposition. These have generally not been developed for irrigated agricultural production. Generally, the soil types used for cotton production are deep yellow-grey and grey-cracking clays. These have developed on the alluvial plains of the Darling River. Underlying these sediments is a marine mudstone base (depth range of 20-100 m). The mudstone acts as a confining layer for groundwater movement and causes groundwater to be highly saline. The effects of which have been seen since the early 1980's, when isolated instances of salinisation first occurred. This is most evident near large earthen water reservoirs and supply channels.

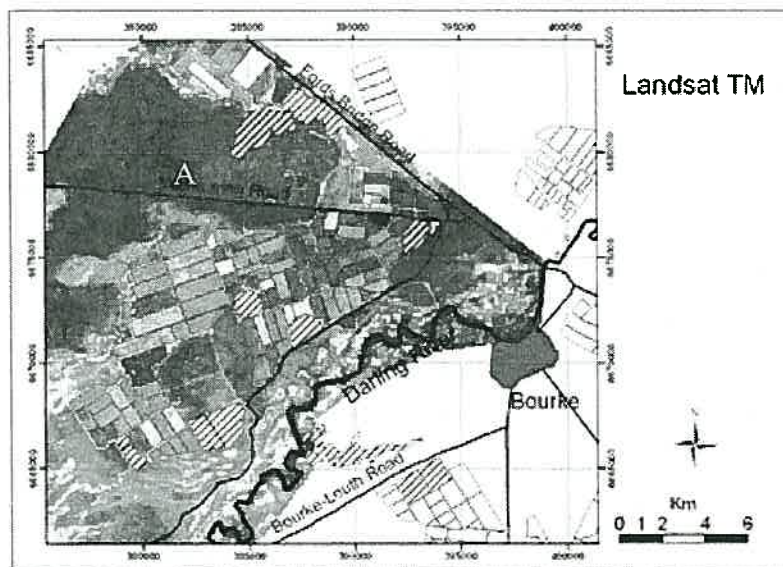


Fig. 1. The Study area is a 300Km² region to the north-west of Bourke

In order to map the groundwater levels and identify the source of the salts ancillary data was collected from numerous sources. This includes ground based, airborne and satellite data. Broadly, the data fall into 3 groups: Electromagnetic (EM), Digital Terrain Model (DTM) and Landsat data. The data was sampled at various resolutions ranging from 60-500 m over the study area which allows predictions of groundwater depth and salinity at far higher resolution than would be possible if traditional methods such as piezometers reading were used.

Ancillary Data

A broad-scale survey was undertaken with EM34 and EM38 instruments. The EM34 measurements were taken at 10 (EM34-10), 20 (EM34-20), and 40 m (EM34-40) coil spacing in the horizontal mode. This gives theoretical bulk EC_a measurements between 0-7, 0-15 and 0-30 m, respectively (McNeil 1992). The EM38 was used in the horizontal and vertical modes with

theoretical measurement to depth of 0.75 and 1.5 m, respectively (McNeill 1980). Measurements were made at an interval of approximately 500 m across irrigated and 1 km in dryland areas.

A digital terrain model (DTM) was derived from airborne data (Department of Mineral Resources- (DMR 1995). The data was collected as part of a radiometric survey; from an aircraft flying at a height of 60 m and 250 m run widths. The DTM was used to derive secondary attributes (e.g. plan and profile curvature) known to influence groundwater levels (Troch et al. 2002).

Landsat TM images were also acquired. The image was taken on May 3rd 1999, at a time when most cotton in the region has been picked or defoliated. The Landsat image consists of 7 bands providing information on reflectance on a wide range of spectra.

Soil and water data

In order to develop calibration relationships between the ancillary data and depth to groundwater, 50 cores were drilled to depth of 12 m. They were analysed for salinity content (i.e. EC_e) and soil texture at 1 m depth intervals. Also noted was the depth at which the profile was saturated. This depth was taken to approximate the groundwater depth. Half of the cores drilled did not reach groundwater levels and consequently these were not used in the calibration of groundwater depth however were used in calibrating EM instruments to predict location of saline subsurface material (i.e. 6-12 m). The shallowest groundwater depths were 5 m below the surface and were mostly found near water storages. Deeper groundwater levels were found underlying the aeolian dunes and near the Darling River.

Results and discussion

Preliminary data analysis

To better understand the location of the saline subsurface material, the data collected along an east-west transect was plotted. Figure 2 shows the clay stratigraphy along the transect. In the western part of the traverse (underlying Aeolian sediments) topsoil clay content is less than 20%. This is similarly the case at the eastern end of the traverse, near the Darling River. Here, clay content was less than 40% to 12m. In between, clay content to a depth of 5m is generally greater than 50%. What is worth noting is a) at a depth of about 12m along the whole traverse, and b) between Eastings of 386000 and 391000 (and to a depth of 12m) clay content is greater than 50%. It is also worth noting the groundwater level coincides with where clay content is less than 40%. EC_e is generally below 4 dS/m at either end, whilst on the clay plain it is less than 8 dS/m in the root zone. As with clay content, EC_e is greatest (i.e. ≥ 16 dS/m) i) at about 12m along the traverse, and ii) between Eastings of 386000 and 391000.

Figure 4 shows a contour plot of the apparent conductivity of the soil (EC_a) collected with the EM38 in horizontal mode. It is evident that the areas associated with irrigated cotton fields have values generally greater than 150 mS/m, this is particularly the case around storages where a leaching/evaporation regime may be occurring. Similar patterns were found with the EM34. There

was a trend for EC_a readings to increase as the coil spacing was increased to 20 m and 40 m, suggesting more conductive material at depth.

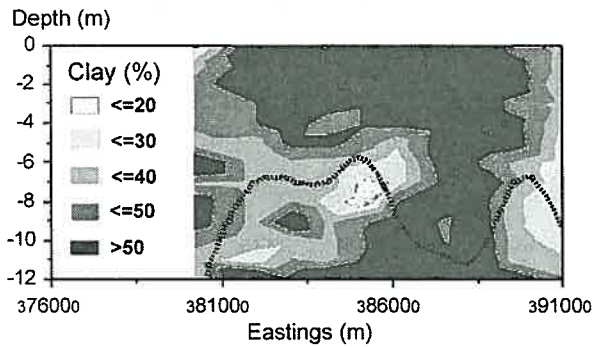


Fig. 2. Spatial distribution of clay content (%). Note: dotted line indicates groundwater levels.

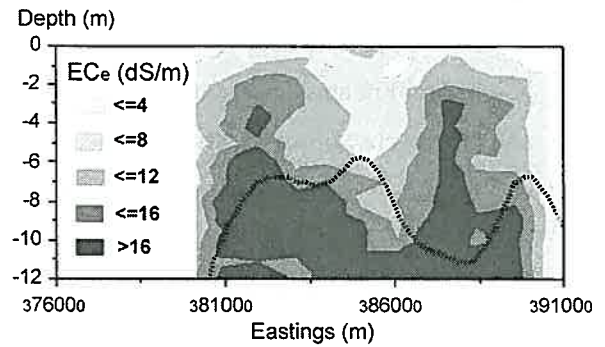


Fig. 3. Spatial distribution of salinity (EC_e dS/m). Note: dotted line indicates groundwater levels.

In order to determine which ancillary variables would be useful predictors of groundwater depth we first established a simple regression relationship between each ancillary variable and groundwater depth. Their degree of correlation is shown by the r^2 values: higher values indicate stronger relationships. The correlations were as follows: EM38-v (0.13), EM38-h (0.12), DTM (0.38), curvature (0.17), plan curvature (0.13), profile curvature (0.15), Landsat band-3 (0.2), Landsat band-2 (0.11). Combining these variables using multiple linear regression gave an r^2 of 0.79. Interestingly, the EM38-h and EM38-v were most suited for predicting groundwater depth of all the EM measurements. Higher EM readings were associated with a shallower groundwater. This is most likely due to the groundwater intermittently rising into the upper profile leaving residual salt and moisture and hence increasing EM readings.

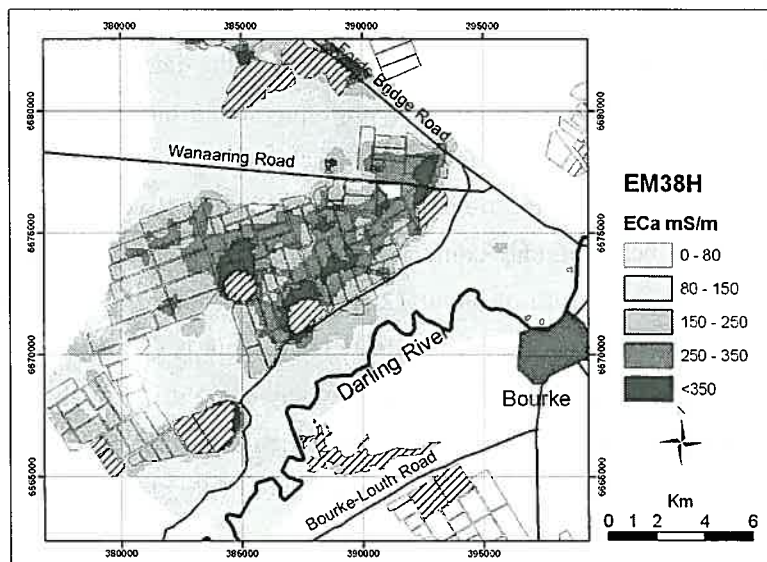


Fig. 4. Spatial distribution of apparent electrical conductivity (EC_a) as recorded by the EM38 in the horizontal mode (EM38-h).

The DTM showed some of the most significant correlations with groundwater depth. This is predominantly due to the influence of the red aeolian sand dunes, which rise some meters above the elevation of the clay flood plains. The higher permeability of these sands means that the

groundwater does not necessarily follow the same upward contour. This results in a relationship whereby as surface elevation increases the depth to groundwater also increases, and is an important predictor for water table depth. The DTM was further analysed to yield other hydrological characteristics. These included: profile curvature and planform curvature which help explain how fast water may move and where it may converge respectively (Moore et al. 1991). Further analysis was undertaken to give flow direction and flow accumulation however it was found that only the curvature derivatives gave fairly good correlations with groundwater depth. This reflects the localized nature of the groundwater examined here, where small changes in curvature mean water may have more time to infiltrate and increase groundwater levels. It is also due to the fact that most of the recharge is due to irrigation which does not relate to landscape scale flow accumulation but is anthropogenic in nature.

All of the Landsat bands except for band 4 showed some degree of correlation with groundwater depth, however the correlation of band 2 (green) and 3 (red) was strongest and hence used to make predictions. Both bands showed a decrease in reflectance as depth to groundwater increased, associated with the less reflective areas of the red dune areas and regions adjacent to the Darling River. This relationship may also be a function of the farming practices whereby the reflectance from the land surface is increased because all crops and vegetative matter have been removed.

Prediction of Groundwater Depth

In order to predict groundwater depth a regression equation was developed using the remotely sensed data and the measured groundwater from the soil cores. Figure 5 shows the prediction map of groundwater depth over the study area. What can be seen is that for almost all of the study area groundwater depth sits well below 98 meters AHD (Australian Height Datum). Given that the land surface for most of the study area is between 101-103 meters AHD this means that under current conditions the groundwater will not interact with crop roots because it is greater than 2.6 meters from the land surface, a depth at which cotton crops can no longer derive water (Wallender et al., 1979).

The exception to this are the areas immediately adjacent to water storages which have groundwater levels approaching the ground surface. What is also evident is that there is a general trend for the groundwater to be slightly elevated beneath irrigated areas, particularly in the immediate vicinity of water storages. Interestingly the groundwater depth remains much deeper to the east of the semi-circular storage, this is probably due to a change in soil texture where much higher clay content has prevented water movement. The groundwater level also rises slightly beneath the sand dunes, this is because the topography of the land rises with the dunes and the groundwater level increases slightly in sympathy with this. A general trend for groundwater to slope towards the Darling River was also found, which may lead to some lateral flux of groundwater to the river, however the gradient is low so flux would most probably be minimal.

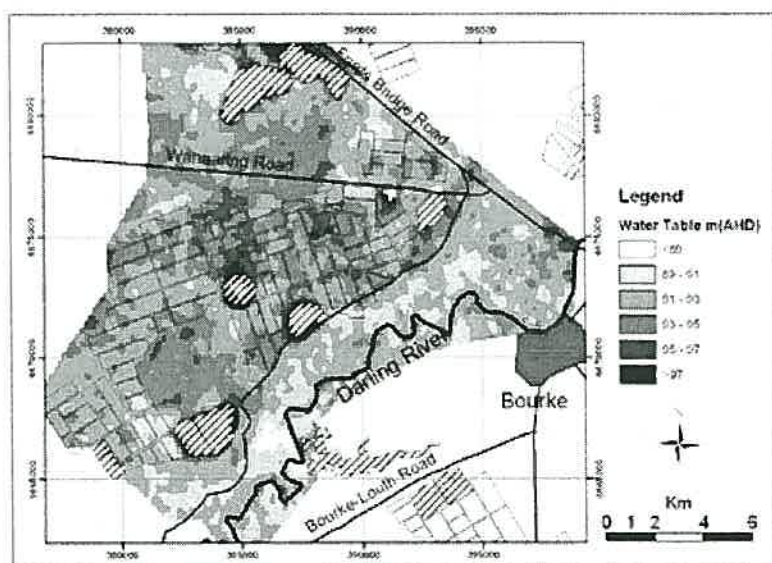


Fig. 5. Predicted groundwater depth using the ancillary data.

The accuracy of the predictions was assessed by calculating the root mean square error (RMSE), a measure of the overall precision of prediction. It was found that when using the ancillary data the RMSE was within 0.7 m of the actual measured groundwater level. This gives us reasonable confidence in the spatial distribution of water table height shown in Figure 5. This information can be used to highlight areas where crops are accessing groundwater as part of the requirements and other areas that may require remedial action where groundwater levels are too close to the surface. From a monitoring perspective this information could also be used to locate suitable locations for installation of water monitoring equipment such as piezometers and C-probes.

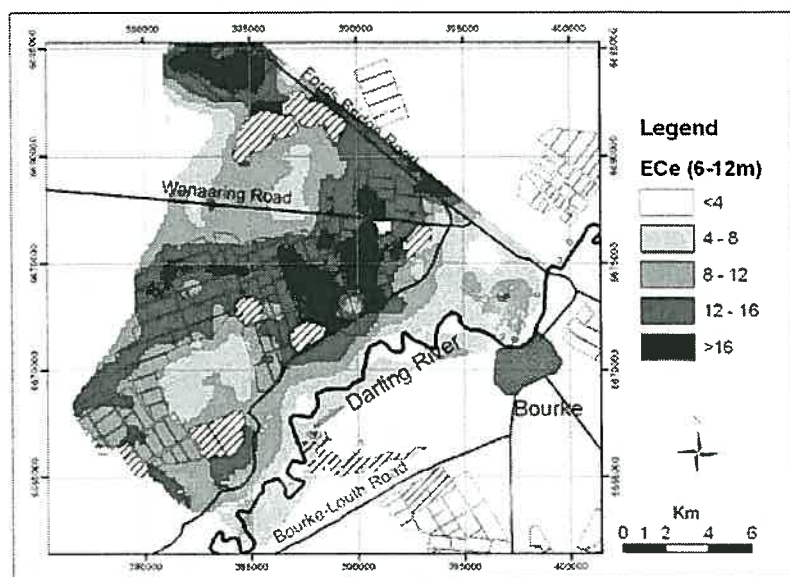


Fig. 6. Spatial distribution of predicted average EC_e between 6-12 m derived from EM34 data collected at 40 m coil spacing (EM34-40).

Predicting location of subsurface saline material

To assess how the groundwater depth influences soil salinity levels two approaches were used; firstly individual cores were analysed to help understand the process of salinisation, and secondly an EM survey was undertaken to locate overall salt stores. Firstly average EC_e was calculated for all samples above and below the water table for each of the 25 calibration profiles. What was found was that 68% of the cores showed a significant increase ($P < 0.05$) in salinity levels below groundwater level. That is, salinity levels averaged 8.8 dS/m above the water table, and 15 dS/m below. The implications of this are that the greatest salt stores are located below the level of groundwater. Therefore, changes in groundwater levels are the most likely mechanism that salts are mobilized into the root zone. From a practical point of view and because the groundwater is too saline to be of any use to cotton production, it must be kept below 2.6 m (Wallender et al., 1979).

Further analysis showed that another process was occurring in the group of profiles where salinity was not significantly higher ($P < 0.05$) below the groundwater level. These profiles were significantly higher in sand content, around 29%. This suggests that in these profiles excess deep drainage may be occurring from irrigation practices. This vertical movement of water is arrested by the heavy marine mudstone that acts as a confining layer, but at the same time acts as a significant source of salts (see Figures 2 and 3). The result is the creation of a water table which mobilised stored salts. The most likely source of the deep draining water is from reservoirs and supply channels. This is supported by the fact that most of the uniformly non-saline EC_e profiles were located in close proximity to supply channels or the Darling River.

To better understand how salinity levels relate to the predicted groundwater depth across the entire study area a relationship was developed between the EM34-40 readings and the average value of EC_e between 6 and 12 meters ($EC_{e(6-12m)}$). This was done because at this depth the saline subsurface material is most prevalent.

Predicted salinity levels can be seen in Figure 6. It is evident that the most saline subsurface material coincides with the area developed for irrigated cotton production. Salinity beneath the aeolian dunes appears comparatively low when compared with the rest of the landscape. Interestingly these areas also show a slightly elevated groundwater levels (Figure 5). This could point towards a long term leaching regime in these more permeable soils where historically heavier rain events may have leached salts from these areas, similar to the process found when examining the sandier calibration cores. Salinity levels decrease towards the Darling River despite clay levels remaining relatively high. This may be a function of an expanding and contracting freshwater lens from the Darling River that has historically seen dilution occur.

Conclusions

Knowledge of groundwater depth is an essential element of farm management, particularly in areas where groundwater is saline and has the potential to affect crop yield. In order to obtain this information in the Bourke Irrigation District we used ancillary data (e.g. ground based EM and

DTM data derived from airborne survey and Landsat TM data) to predict groundwater levels from 25 calibration holes. We found that we could predict groundwater levels to within 0.7 m. In terms of the spatial distribution of groundwater levels, our predictions suggest that beneath irrigated cotton areas, particularly around water storages, groundwater levels are shallower than beneath non-irrigated land. This is consistent with land that exhibits visual signs of salinisation. This suggests that excess water is percolating beneath these structures and mobilizing stored salts into the rootzone.

The method of predicting groundwater levels offers many benefits for natural resource management. It offers an estimate of water table depth at a very high resolution (every 100m) which would not be feasible at such a scale using traditional methods such as piezometer measurements. Secondly the scale of prediction allows for even isolated areas of high water table to be identified before visible signs of stress appear on vegetation. It must be noted however that this approach only offers a “snapshot” of groundwater conditions experienced at the time of sampling. It is not suited to ongoing monitoring but rather helps to get an understanding of overall hydrological conditions and areas that may require further investigations or further monitoring equipment to be installed. We recommend the establishment of a monitoring network in order to collect information (e.g. groundwater fluctuation) to better understand the overall hydrological dynamics and hence determine best irrigation management strategies in the Bourke Irrigation District.

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