CHARACTERISING THE SPECRTAL SIGNAL OF DISCHARGE ZONES AT THE MARGIN OF THE GREAT ARTESIAN BASIN.

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Abstract

Diffuse discharge along the southwest margin of the Great Artesian Basin is thought to be an important, but currently poorly understood, component of the Basin's water budget. Remote sensing data are being investigated as a tool for mapping the salt and soil moisture variations associated with diffuse discharge zones, in order to assist in scaling up of field based discharge measurements to regional diffuse discharge estimates. The discharge zones have been segregated into four conceptual discharge scenarios which relate subsurface processes and variation in discharge rates, with expected observable surface characteristics. A handheld soil moisture probe ("Hydraprobe") was used to collect surface soil moisture and conductivity data from the top 5 cm soil layer to ground-truth a number of processing methods applied to the satellite data. The Hydraprobe data were analysed to investigate the relationship between soil moisture and salinity at the ground surface. Hydraprobe data showed areas non-saline areas exhibited a uniformly low soil moisture content, consistent with the conceptual model of the discharge zones. Average field soil moisture and salinity data generally correlated well with landforms. Landsat TIR data showed a correlation with field data over the discharge area. This response was inconsistent between satellite images and it is presently unclear what the response in TIR data relates to. The Landsat Band7/Band1 salt ratio showed the strongest correlation to landforms characterised by salt at the surface and results suggest the salt ratio will be useful in distinguishing discharge zones.

Introduction

The Great Artesian Basin (GAB) is Australia's largest groundwater system, and one of the largest in the world, underlying approximately 22% of the continent (Habermehl, 1980). The GAB is the only reliable source of water for agriculture and industry in parts of arid and semi arid central and eastern Australia. Discharge from the basin is thought to be concentrated along its south west margin, where the aquifer is either outcropping or brought close to the surface by folding and faulting. In these areas higher rates of water are lost from the GAB than in deeper aquifer settings. In shallow settings the vertical leakage feeds local water tables, and is then lost to evaporation.

Little work other than Woods *et al* (1990) has been carried out investigating the spatial distribution of rates associated with diffuse discharge or factors controlling this process, with large gaps existing in the knowledge of this significant component of the GAB water balance. Currently an ARC linkage project is collecting field based, point scale estimates of ET using a number of methods. The study is designed to cover the variation in discharge settings over the project area. In light of the new data from this project and process understanding, methods to scale up discharge rates need to be investigated.

We have divided the margin of the GAB into four scenarios in terms of discharge processes. These four scenarios form a conceptual framework on which to base hypotheses on expected surface characteristics for each scenario. The expected surface expressions of each scenario are then used as a basis to test the applicability of remote sensing in distinguishing the discharge scenarios. These four scenarios are described in the diagram below, which relates the expected surface characteristics of each scenario to the subsurface discharge process, which are ultimately related to rates of evaporation.

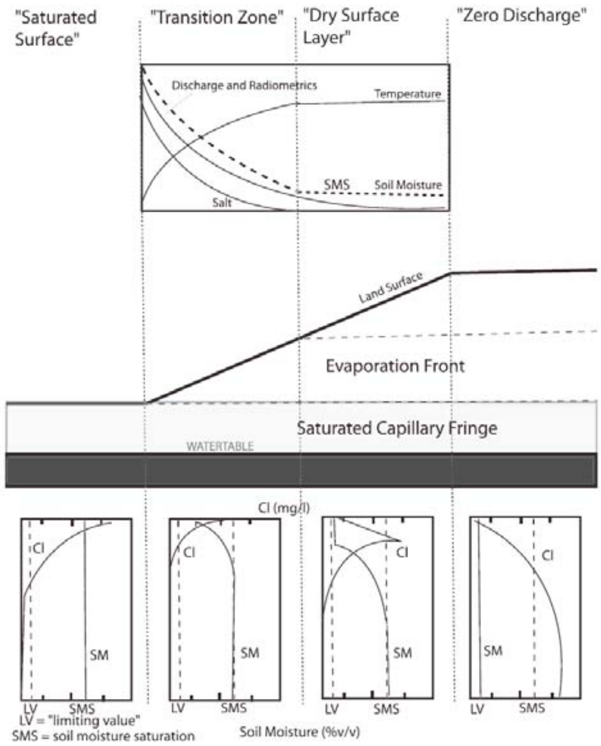

Figure 1 shows how surface characteristics (soil moisture, salinity and temperature) relate to discharge rates as a function of topographic relief (or depth to groundwater table). Four conceptual discharge scenarios defined by subsurface process are used to classify discharge zones based on surface characteristics.

The first scenario (fig 1) describes areas where the ground surface is saturated, and the rate of water transported by capillary rise can meet the evaporative demand. These areas are found where the depth to groundwater is shallow enough to allow the capillary fringe to remain saturated to the surface. As saline groundwater evaporates at the surface, salt is precipitated. This typically leads to a thick salt crust forming at the surface (Rose *et al* 2005). The temperature at the surface will be lower than surrounding areas due to soil moisture and the albedo of the salt crust.

The second scenario, the ‘transition zone’, describes areas where the ability of the soil to transport water through capillary rise does not meet the evaporative demand at the surface. This causes a liquid – vapour discontinuity, known as the evaporation front (Rose *et al* 2005). Since water moves in both liquid and vapour phases, the soil moisture (liquid) at the surface will be less than saturated. The soil moisture will decrease moving through this zone, until it reaches the ‘limiting value’ which is the ‘background’ soil moisture for a given soil type. Once the liquid – vapour discontinuity occurs, the hydraulic conductivity of the soil diminishes, further lowering the rate of discharge (*ibid*). Soil moisture at the surface and albedo from precipitated salts both decrease the temperature at the surface. The temperature increases in this area as the soil moisture and salinity values decrease.

The third scenario is referred to as ‘the dry surface layer’ which defines areas where discharging water at the surface is only transported in the vapour phase. Soil moisture is at the ‘limiting value’ between the surface of the DSL and the start of the evaporation front. Discharge still occurs here, but is often at least an order of magnitude less (Costelloe *et al* 2008) than in the saturated and transition zones. Salt is not precipitated at the surface in these areas. Heat from the surface is driving evaporation occurring in the subsurface, therefore it is possible the temperature at the surface is diminished to some extent in these areas compared with areas of zero discharge.

The fourth scenario encompasses areas with “zero discharge”. In reality it is likely that some water is lost in these areas (Woods *et al* 1990). However these rates are assumed to be so low as to be considered insignificant when compared to the previous three discharge scenarios. In these areas, at the surface, soil moisture is at the ‘limiting value’ and soil salinity is low (fig1).

This paper presents the initial results from an investigation of how Remote sensing of these hypothesised surfce expressions can be used to distinguish these various discharge scenarios. This will be done through analysis of ground sample data measuring characteristics which satellites can measure and an initial investigation into how response in Landsat images over the discharge zones relate to ground truth data.

Study Area:

Two discharge areas associated with mound springs at the margin of the Great Artesian Basin are studied here. Both sites are north of the Gammon Ranges, which form the northern Flinders Ranges.

Public House Springs is associated with the GAB aquifer which outcrops against the proterozoic basement forming the Gammon Ranges (Figure 2). The discharge zones here at typically associated with low lying areas in the landscape, either where the GAB sandstone outcrops or where the aquifer is buried under shallow layers of the overlying bulldog shale. Some discharge zones are found higher in the landscape along the contact of outcropping GAB aquifer and the basement rock. The discharge zones tend to form flat salt crusted and fairly moist clay plans. These zones are typically surrounded by sand dunes, drainage channels, rocky outcrops and rises.

About 30km to the north, Reedy Springs are associated with a large domal anticline structure which brings the GAB aquifer close to the ground surface (Figure 3). The moundsprings form large domes with most of the high rate discharge presumably occurring on this landform. The surrounding landforms are predominately gibber plains and large erosion channels caused by water from the moundsprings.

Methods

Transects were constructed to intersect major landforms across the discharge zones. A handheld Hydraprobe (Merlin *et al* 2007) was used to collect soil moisture SM and bulk soil Electrical Conductivity (EC) data. Soil samples were collected at every second Hydraprobe location to calibrate the Hydraprobe SM data with lab gravimetric analysis. Soil samples were also used for lab 1:5 salinity measurements (Lovejoy 1974). Landform mapping was carried out in areas surrounding the transects.

Two Landsat 7 images were obtained for analysis. The Public House Springs image was aquired on the 7/7/2001 and the Reedy Springs image was acquired on the 17/5/2000. The digital number was extracted for each pixel corresponding to a Hydraprobe location. The digital number for each Landsat band was plotted against the soil moisture value at that location, and a regression analysis applied to each group.

Figure 2 – Landsat RGB – 731 image highlights salt affected areas at Public House Springs in blue.

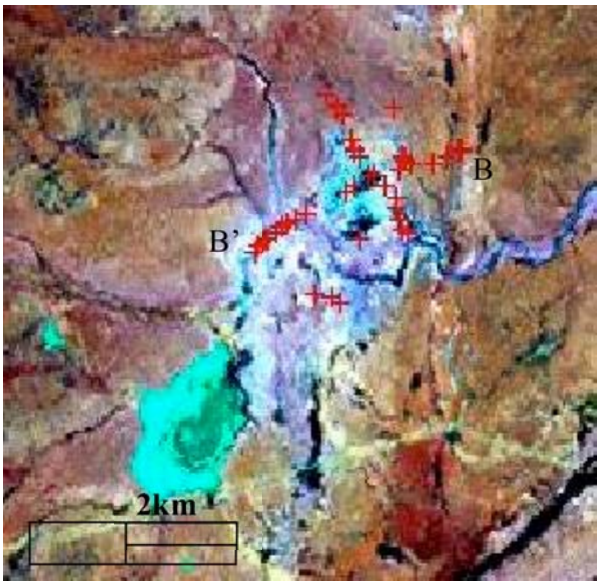

Figure 3 Landsat RBG – 731 image highlights salt affected areas at Reedy Springs in blue. Two perpendicular transects radiate from the main discharge zone.

Results

At each Hydraprobe location it was noted whether or not visible salt occurred at the surface. The Hydraprobe moisture data is split into two groups, defined by whether or not visible salt is present. Comparing Hydraprobe soil moisture to lab soil moisture showed reasonable correlation for lab moisture measurements with Hydraporbe values of less than 25% w/w. Above this value no correlation is evident, and therefore these Hydraprobe readings are discarded. A Kolmogorov-Smirnov test was applied using the two data sets to statistically assess if the data sets are significantly different. By investigating the relationship between visible salt and soil moisture as measured by the Hydraprobe, we can determine whether or not the Hydraprobe's moisture data is likely to add more information on discharge processes than what we can obtain using visible salt and satellite data.

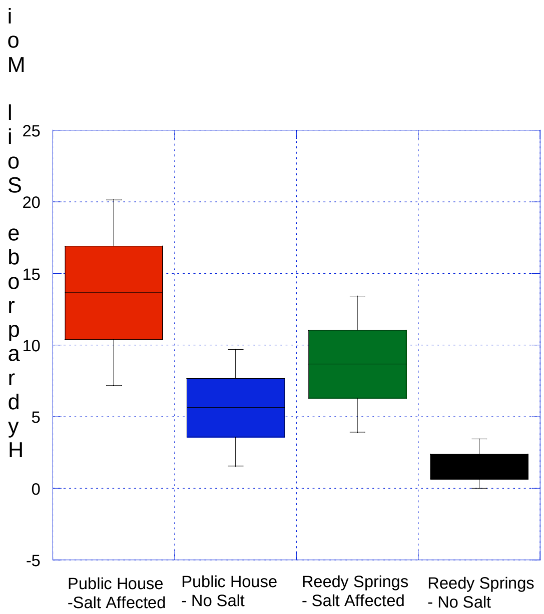

Figure 4 – Hydraprobe samples corresponding to locations with salt at surface and without salt are statistically compared using a Kolmogorov-Smirnov test. Plot shows mean soil moisture for each data set, and one standard deviation from the mean.

Hydraprobe statistical analysis showed that areas with no salt had a uniformly low soil moisture, where as areas with salt had a higher soil moisture average, but featured very large variation in soil moisture values. These Hydraprobe data have not been calibrated specifically to these site conditions. Sample locations in salt scalds are often characterised by hypersaline soil water. These extreme salt conditions can potentially have an effect on the dialectric content, which the Hydraprobe uses to estimate both soil moisture and salinity (Merlin *et al* 2007). It is possible that this effect on the dialectric constant is causing erroneous readings in the salt affected landforms. Erroneous Hydraprobe values were omitted, and therefore the mean and standard deviation for salt affected areas are likely to be larger than results presented, which is still consitent with the interpretation.

Transects were plotted against Landsat TIR data and soil moisture, and overlayed with landform information. A band ratio (Band7/Band1) was calculated from the Landsat data which aimed to highlight salt pixels by way of the high reflectance in salt associated with the blue band, and the absorption feature in the 2200nm band. TIR data is then plotted against the 'salt ratio'.

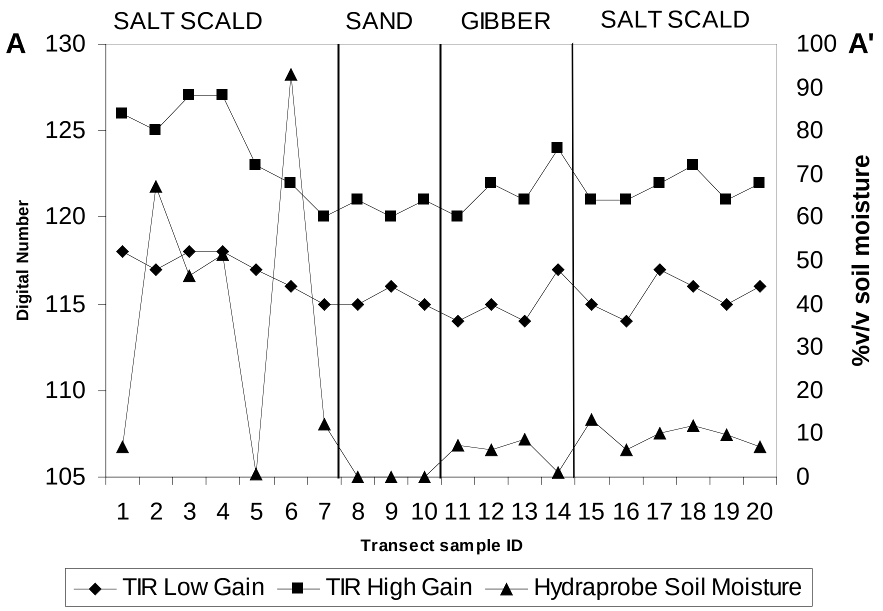

Figure 5 - Hydraprobe soil moisture data and Landsat TIR for Public House Springs transect.

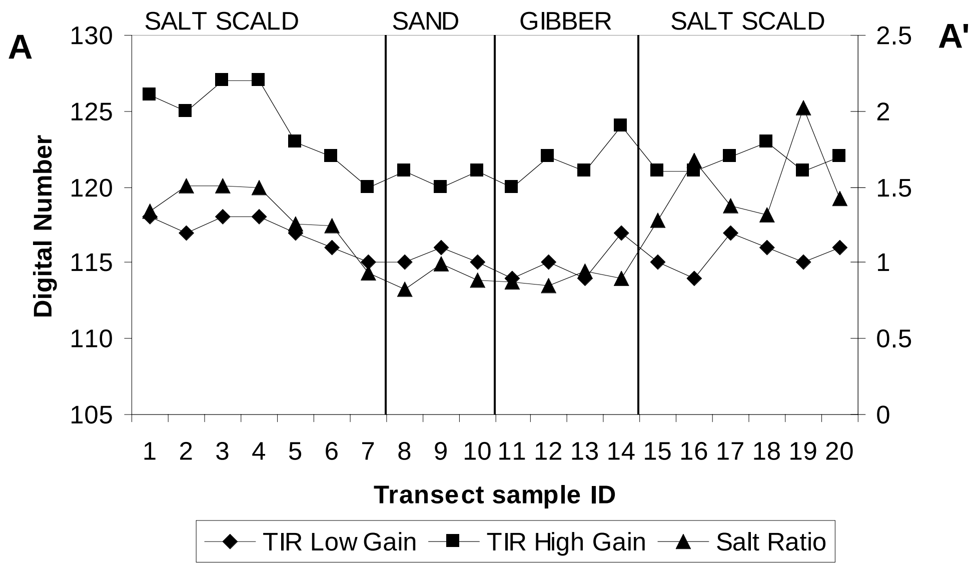

Figure 6 – Salt ratio and Landsat TIR plotted along the Public House Springs transect.

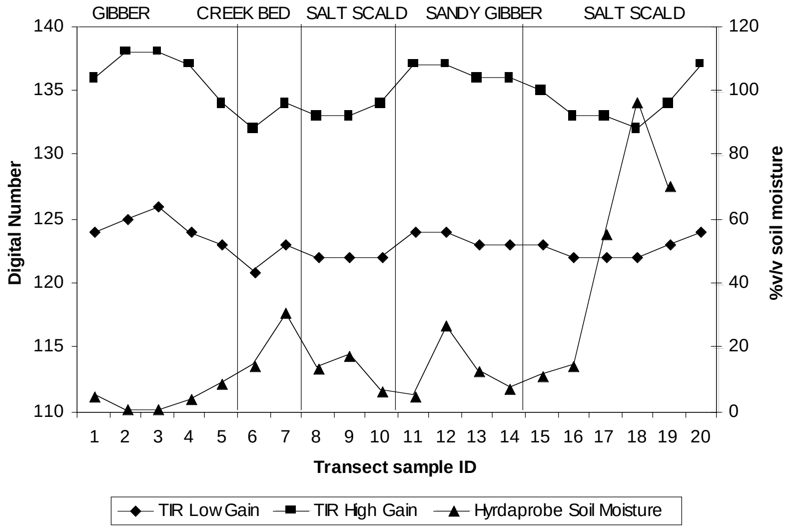

Figure 7 - Hydraprobe soil moisture and Landsat TIR plotted along the Reedy Springs transect.

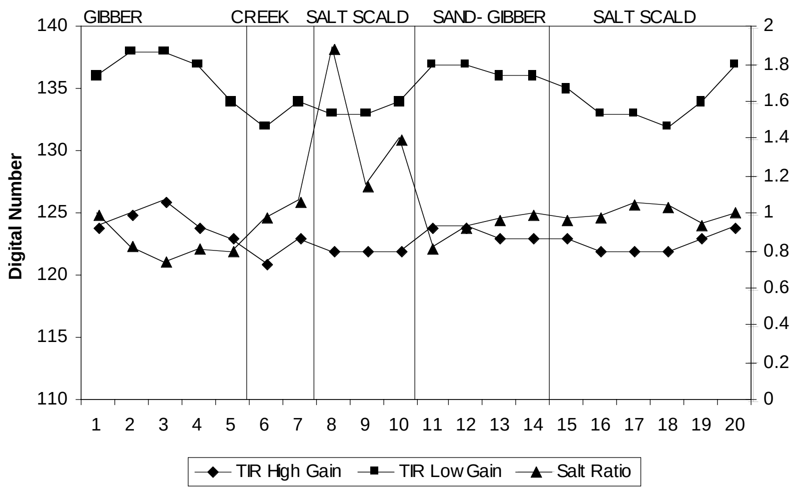

Figure 8 - Landsat band 1/band 7 – 'salt ratio' – plotted with Landsat TIR along the Reedy Springs transect.

Results are presented for two transects "PH" and "RS" which show the difference in TIR and albedo response from two different Landsat Satellites. Transects displayed are chosen as they show the variation between Landsat images in the correlation between TIR and SM most clearly. Omitted transects follow the same respective trend for the satellite image used for its analysis. At Public House Springs soil moisture shows some positive correlation with TIR data. Major landforms along the transect are overlayed here, and show quite distinct correlation with variation in soil moisture and TIR data. The uncalibrated Hydaprobe data shows grossly exaggerated soil moisture values in one of the salt scalds, but most likely reflect the high variation and high values found in this landform. The salt ratio along the Public House Springs transect showed high average values for both salt scalds. Hydraprobe soil moisture data at Reedy Springs shows a general negative correlation with Landsat TIR data. Major landforms show a reasonable correlation between soil moisture and TIR data. Salt ratio shows negative correlation with Landsat TIR data at Reedy Springs, and high average values corresponded to areas mapped as salt affected.

Discussion

This paper presents a conceptual framework describing groundwater discharge from the south-west GAB and resulting characteristics of the surface. Field observations and the soil moisture field data are consistent with the hypothesised surface characteristics, with low and limiting value soil moisture outside of salt affected areas. Within the salt affected areas (i.e. transition and saturated zones), the field soil moisture data exhibits a higher average value compared with non-affected areas but displayed high variability. It is unclear to what degree soil moisture can be used to identify the transition zone from saturated zones.

Point scale soil moisture did show some correlation with TIR data along transects. The high variability at small scales (as shown by statistical analysis) means that there are difficulties in comparing point scale estimates to TIR data which has an 80m resolution. Soil moisture and ‘salt ratio’, in both transects, were generally positively correlated to each other.

The TIR response for Public House springs showed a positive correlation to both soil moisture and ‘salt ratio’, whereas at Reedy Springs a negative correlation was exhibited. This is possibly due to the fact that the TIR data was derived from two different satellite images which were taken on different dates. This difference may be due to effects of thermal inertia differences with moisture content and differences in ground heating rates between the two dates on which the images were taken. If this were the case, it would suggest that soil moisture does have a significant but complicated effect on TIR emissivity and the response is not only dominated by albedo due to salt crusting. Presently it is unclear how soil moisture is related to the TIR response in the Landsat images.

Salinity measured from soil samples showed the same problem of high variability at small scales (evidenced by large fluctuations from point to point), presenting a scaling problem when comparing to Landsat data. Plotting the salt ratio with landform data shows that average trends in the salt ratio correspond well with landform boundaries. The salt ratio showed the strongest correlation to landforms, in that high values occurred in landforms mapped as characterised by salt at the surface.

Results suggest that the DSL and ‘no discharge’ zones can be identified as areas with no salt at the surface but not distinguished from each other, as these areas show a uniformly low soil moisture assumed to be at the limiting value. Salt via its response in visible bands, and soil moisture presumably affecting TIR can be used to delineate the extent of saturated and transition zones.

Conclusions

Ground truth soil moisture data is valuable in distinguishing saturated zones and transition zones from the DSL. Results from the Hydraprobe analysis were consistent with the conceptual hypothesis of surface characteristics in that areas without salt (i.e. Dry Surface Layer) exhibit uniformly low soil moistures, presumably at the limiting value.

TIR data does appear to respond over discharge areas. However the response appears to be affected by factors in addition to salinity and soil moisture, such as atmospheric temperature, which varies between Landsat images depending on when they are acquired. Presently we cannot explain the existence of a negative or positive correlation.

The salt ratio has a strong correlation with landforms characterised by salt at the surface. Results suggest that satellite data will be useful in mapping the extent of saturated zones and transition zones. It is presently unclear to what degree satellite data can be used to differentiate between the two, or what degree variation in the transition zone can be delineated. It is also unclear to what degree satellite data can be used to differentiate between the DSL and no-discharge zones.

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