

DETERMINE SALINISATION POTENTIAL IN THE LOWER MACQUARIE VALLEY

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Introduction

Irrigation is an indispensable technology used to augment agricultural production in the semi-arid and arid regions. However, poor water management (*eg.* unsuitable location of reservoirs) can lead to the creation of perched water tables and secondary salinisation. In some irrigated areas in the northern Murray Darling Basin, point-source salinisation has occurred (Triantafilis *et al.*, 2003a) whilst in others there is little or no evidence. This is because waterlogging and salinisation occur as a function of interactions between various biophysical factors such as agronomy, geology, hydrology, climate and topography.

In order to determine where these problems may arise, biophysical features that are influenced by agronomic practices need to be generated. Stored in Geographic Information Systems (GIS), the interaction between biophysical data layers can be related to where salinisation occurs, and where these conditions may be met elsewhere. Recently airborne geophysical methods have been used to develop layers (*eg.* National Dryland Salinity Program). The start up-cost of around \$7-12/ha is prohibitive. Alternatively, salinity hazard and risk maps are being produced at catchment level (*e.g.* State Government Agencies) using qualitative soil/geology data and land use information. The results may lead to maps of low accuracy/interpretability. A major reason for this is that weightings given to particular biophysical layers are subjective (*i.e.* assigned by so-called experts).

In the following paper we describe the development and spatial distribution of deep drainage (*DD*) risk, average clay content (0-7 m) and average salt store (0-10 m) in the cotton growing districts of Trangie and Warren in the lower Macquarie valleys of central New South Wales (see Figure 1). By doing this we mapped individual biophysical layers thought to contribute to the causes of water logging at a site where soil salinisation was first reported in the Trangie district in the early 1980's. Critical values thought to cause salinisation were determined: a) *DD* risk is greater than 0.5 beneath water reservoirs; b) average clay content (0-7 m) > 38 %; and, c) average salt store (0-10 m) > 2.5 dS/m. By using GIS type analysis we mapped where these three conditions would be met and hence create salinity hazard maps associated with the construction of reservoirs. The results are consistent with areas where salinity has been experienced. The maps also indicate where best management practices developed in Trangie district could be extended.

Materials and methods

Study area

The Macquarie River is a tributary of the Darling, which drains the northern part of the Murray-Darling Basin. The study area is located in the lower Macquarie valley southeast of the townships of Warren and Trangie (Fig. 1) and includes both irrigated and dryland farms. The latter is mostly wheat production and native pastures. Irrigation is mostly for cotton production. The irrigated infrastructure (including major water reservoirs) of the area is shown in Fig.1.

McKenzie (1992) identified several Pedodermis in the Macquarie valley (Figure 2). The Trangie Cowal Pedoderm is characterised by the Wilga red-brown profiles (Red Chromosol) and Byron red-brown earths (Red Chromosol). Both are characterized by distinct clay maxima between 0.30 and 0.80 m. The Gin Gin profiles (Red Dermosol) of the Gin Gin Pedoderm, are strongly weathered with a uniform to gradational texture profile. The Macquarie profile class (Stratic Rudosol) defines the Macquarie Pedoderm. It has minimal development and is characterised by considerable fine sand and silt fractions; moderately high cation exchange capacity and a permeable nature. The Mitchell profile class characterizes the Old Alluvium Pedoderm - Meander Plain, where the well-drained profiles (Red Chromosol) contain high coarse sand content. The poorly drained profiles (Red, Yellow or Grey Sodosol) are sodic by comparison. The Backplain is more variable and includes: Mullah - dark grey to black cracking clays (Black Vertosol); Snake - sodic grey cracking clays (Grey Vertosol); and, Buddah profiles (Red Vertosol) characterized by high clay content of which smectite and kaolinite are co-dominant with illite.

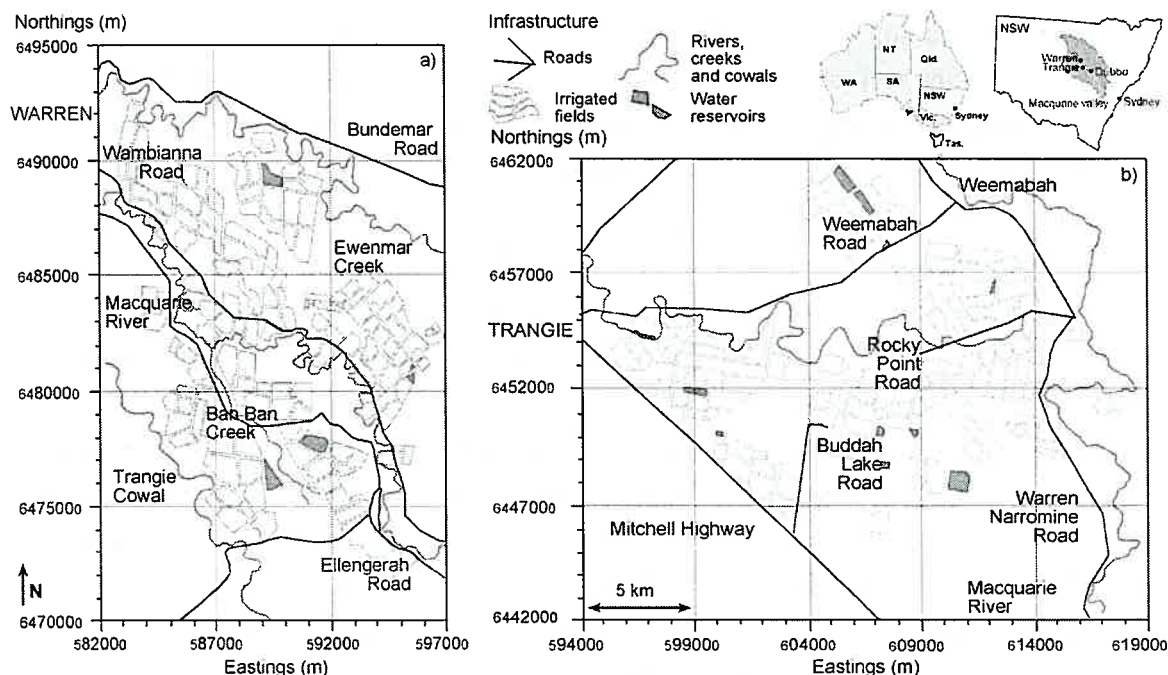


Fig. 1: Location of lower Macquarie valley and major infrastructure near a) Warren and b) Trangie.

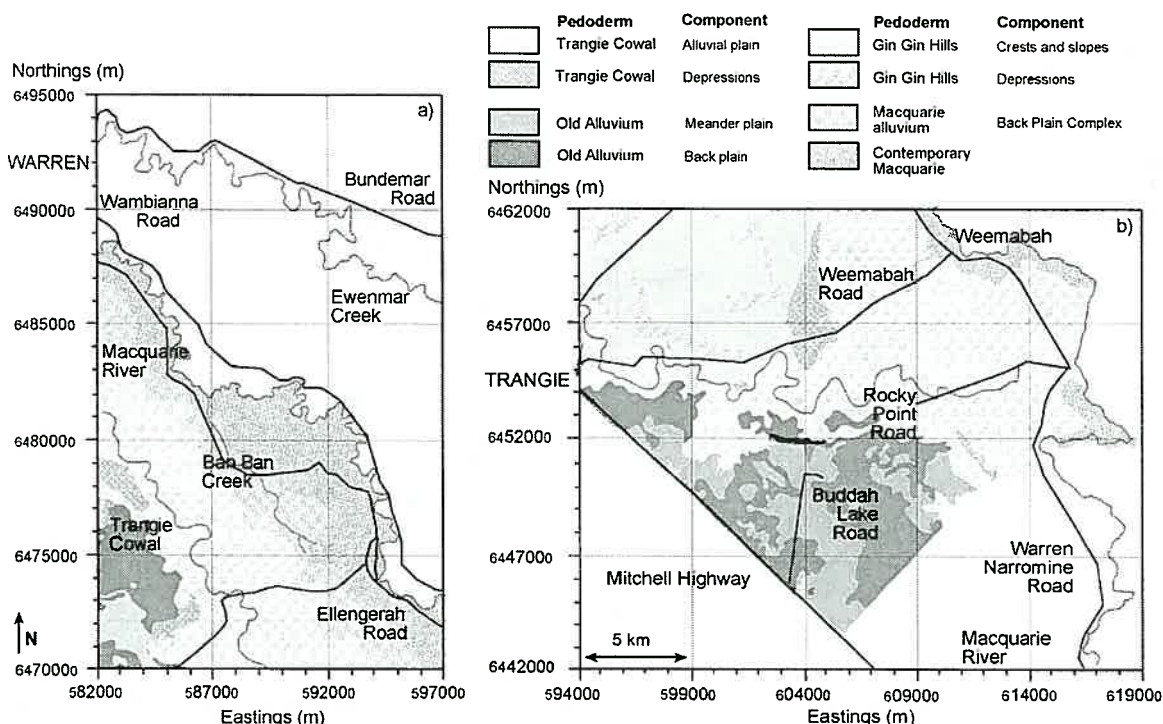


Fig. 2: Pedoderm in the lower Macquarie valley (after McKenzie, 1992) near (a) Warren and (b) Trangie.

EM surveys

In order to confirm whether EM data could discern these soil patterns and potentially the spatial distribution of hydrological features in these landscapes, EM34/38 surveys were undertaken. Briefly, EM instruments work by measuring the strength of electromagnetic fields (i.e. primary and secondary) induced into the soil. The strength of the secondary field is a function of: a) amount of negative charge; b) clay content; c) concentrations of salts in solution; and, d) moisture content (Triantafyllis et al., 2000, 2001 and 2002). The more conductive the soil, the greater the secondary electromagnetic field produced (Williams and Hoey, 1987) and measured as soil electrical conductivity (EC_a -mS/m).

In both areas 500-metre grid spacing was used. The Warren survey included 564 measurement locations. In the Trangie district 755 sites were visited. The EM34 survey consisted of taking three measurements in the horizontal mode of operation at coil spacing of 10, 20 and 40 m (EM34-10, EM34-20 and EM34-40). The theoretical depth of measurement is 7, 15 and 30 m (McNeill, 1980). Therefore, the instrument can potentially provide information about the shallow stratigraphy, vadose zone (biologically inactive zone between root zone and water table) and presence of deep saline water tables, (Triantafyllis et al., 2003b). In addition measurements were made with the EM38 in the vertical (EM38-v) and horizontal (EM38-h) modes. The depths of measurement were 1.5 and 0.75 m (McNeill, 1992). The instrument provides information in the agriculturally significant portion of the root zone and subsoil. At each site spatial coordinates were also recorded in the Australian Map Grid (AMG84) using a Magellan NavPro5000 GPS. The location of these survey points is shown in Figure 3.

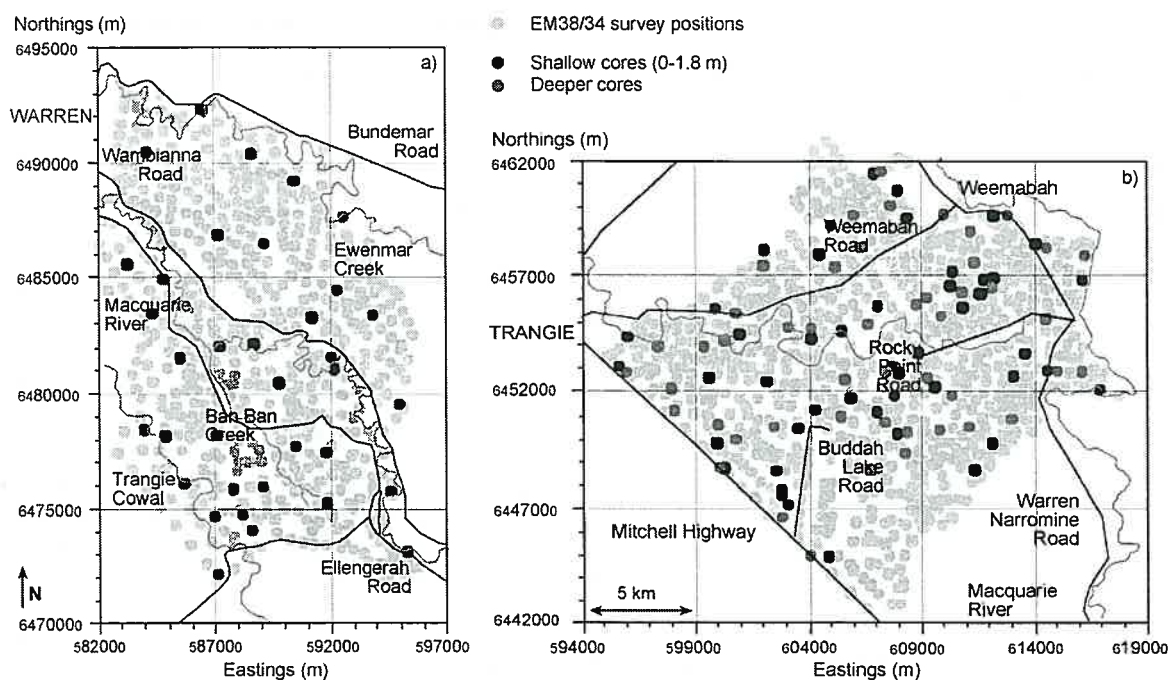


Fig. 3: Location of EM34/38 survey positions and shallow and deep soil sampling cores in (a) Warren and (b) Trangie districts of the lower Macquarie valley.

Soil and water data

Soil samples were collected at the selected sites (Figure 3). This was done essentially at low, intermediate and high values of EC_a . In addition, and to ensure good representation across the area, sites were spread as evenly as possible. A total of 35 deep cores were drilled in the area southeast of Warren with samples collected to a maximum depth of 12 m at 1 m intervals. In the Trangie study area 48 deep cores were collected to a depth of up to 15 m and similarly sampled at 1 m depth increments. In both surveys soil was also collected at 0.30 m depth increments to 1.8 m from each deep core. In addition, to the deep cores collected in the Trangie district, 48 shallow cores were drilled and sampled every 0.30 m to a depth of 1.8 m.

Prior to laboratory analysis samples were air-dried and ground to pass a 2-mm sieve. The samples were analysed for: particle size fraction determined using the hydrometer method. The effective cation exchange capacity ($ECEC\text{-mmol(+)kg}^{-1}$) (Tucker 1974) was determined using a mechanical leaching device (Holmgren et al., 1977). This method is preferred for estimates of exchangeable bases (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and ECEC on alkaline soil containing solid phase carbonates (Loveday et al., 1972). Soil salinity was determined for EC_e : where 125 g of soil was weighed and made into a saturated paste according to procedure outlined by the U.S. Salinity Laboratory Staff (1954). The paste was left to stand for a period of up to 12 hours prior to extraction by suction. The EC_e of the soil solution extract was then measured directly. The EC of water samples (EC_{iw}) collected from the Macquarie River was also measured (i.e. 0.41 dS/m).

SaLF simulations

In order to simulate *DD* at each calibration site, soil attribute data were first inputted into the SaLF program (Carlin and Brebber, 1993). For Warren this included clay (%) and ECEC at depths of 0.0-0.3, 0.3-0.6, 0.6-0.9, and 0.9-1.2 m, and exchangeable sodium at 0.9-1.2 m. For Trangie area, data for first three depths were inputted with exchangeable sodium at 0.6-0.9 m entered. The EC_{iw} value for the Macquarie River (0.41 dS/m) was entered; along with Trangie's mean annual rainfall (i.e. $R = 494$ mm). One irrigation ($I = 1,800$ mm/year) simulation was carried out to estimate deep drainage beneath a shallow storage, supply channel or head ditch (Triantafyllis et al., 2003a and 2004a).

Results and discussion

Spatial distribution of root zone and subsoil EC_a

Figure 6a shows the pattern of EC_a for the Warren and Trangie districts as recorded with an EM38-v. Low EC_a (i.e. < 50 mS/m) values are synonymous with: a) coarse sediment of the Trangie Cowal, b) Old Alluvium (meander plain) Pedoderm, which runs in parallel with the Mitchell Highway in the Trangie district, and c) Contemporary Macquarie Pedoderm, adjacent to the modern-day Macquarie River. Conversely, high values of EC_a (i.e. > 100 mS/m) were associated mainly with Old Alluvium (back plain) Pedoderm, which is clayey in nature. However, higher values of EC_a were also obtained on the Trangie Cowal Pedoderm in two locals: a) southern part of the Warren district between the Macquarie River and Trangie Cowal and b) eastern part of the Trangie district in the area bounded by Weemabah, Warren-Narromine and Rocky Point Roads. This is evident around various storages, where isolated instances of salinisation have been reported.

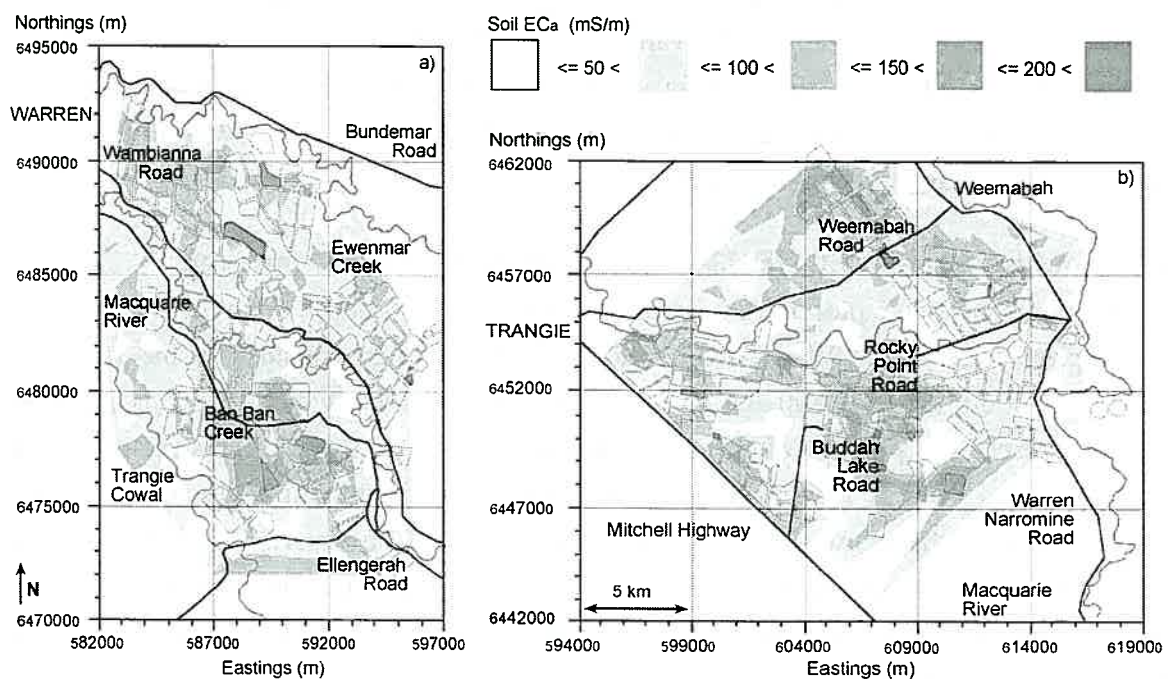


Fig. 4. EM38 signal data (mS/m) in the vertical dipole (EM38-v) configuration as recorded in (a) Warren and (b) Trangie districts of the lower Macquarie valley.

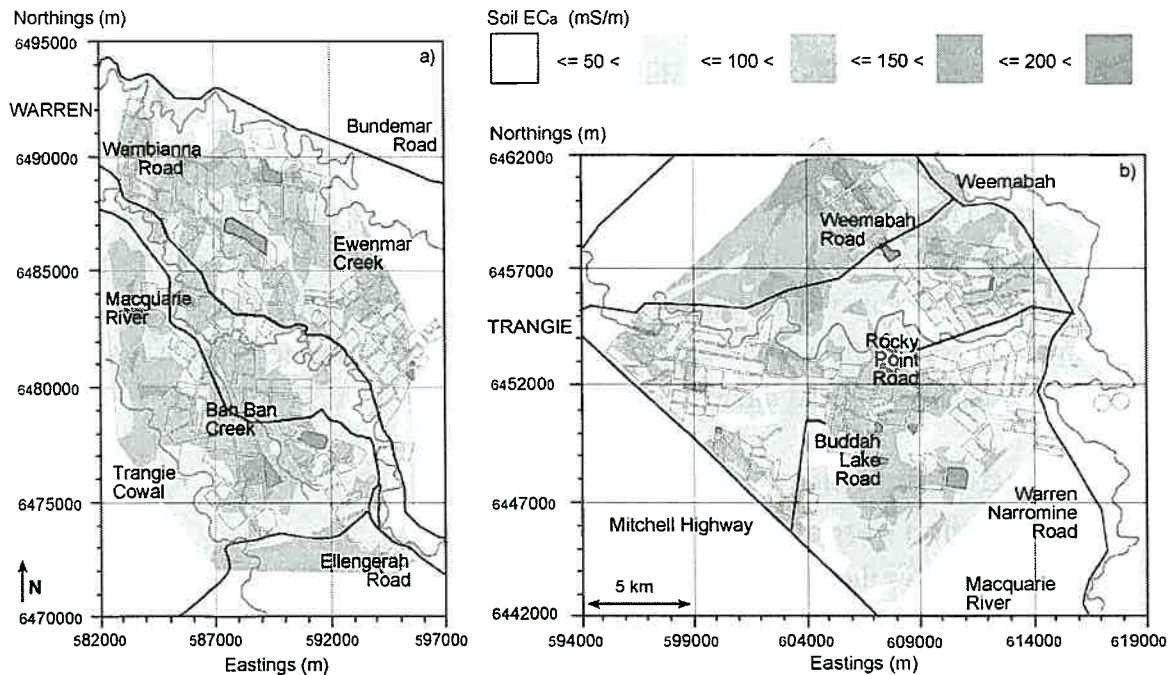


Fig. 5. EM34-20 signal data (mS/m) in the horizontal dipole configuration and 20 m coil spacing as recorded in (a) Warren and (b) Trangie districts of the lower Macquarie valley.

Spatial distribution of shallow stratigraphy and vadose zone (EM34) EC_a

Figure 5 shows the spatial distribution of EC_a obtained by the EM34-20. As with the EM38, the coarser sediments of the Pedoderms of the Trangie Cowal and the Old Alluvium (meander plain) are characterised by low values (i.e. $EC_a < 100$ mS/m), with the lowest (i.e. < 50 mS/m) associated with the Contemporary Macquarie Pedoderm. In the Trangie area the higher values of EC_a (i.e. 100-150 mS/m) were recorded north of the Weemabah Road and in the central southern part of the district between Rocky Point and Buddah Lake Roads. The higher EC_a values (i.e. > 150 mS/m) north of Weemabah Road is consistent with a known saline aquifer within 10-15m of the ground surface in this area. As with the Trangie area, EC_a generally increased with depth in Warren with the patterns similar to those achieved with the EM38.

Relationship between EC_a (EM3-v) and deep drainage (DD-mm/year)

Figure 6 shows the plot of EC_a versus DD (mm/year) estimated using SaLF at each of the sampling sites in the Warren and Trangie districts, when considering the irrigated cotton simulation (i.e. $I = 1,800$ and $R = 494$ mm/year). The low values of EC_a (i.e. < 100 mS/m) represent soil profiles where DD is high (i.e. > 200 mm/year). This includes soil types associated with; a) Trangie Cowal (Wilga soil), b) Old Alluvium (Mitchell soil) and c) Contemporary Macquarie (Macquarie soil) Pedoderms. Conversely, higher EC_a values characterise soil where DD would not generally exceed 50 mm/year and relates to the back plain of the Old Alluvium Pedoderm (Mullah, Buddah and Snake soils). The estimates of DD achieved here are consistent with the results reported by McKenzie (1992) and Willis et al. (1997) on the regional scale in the Macquarie valley.

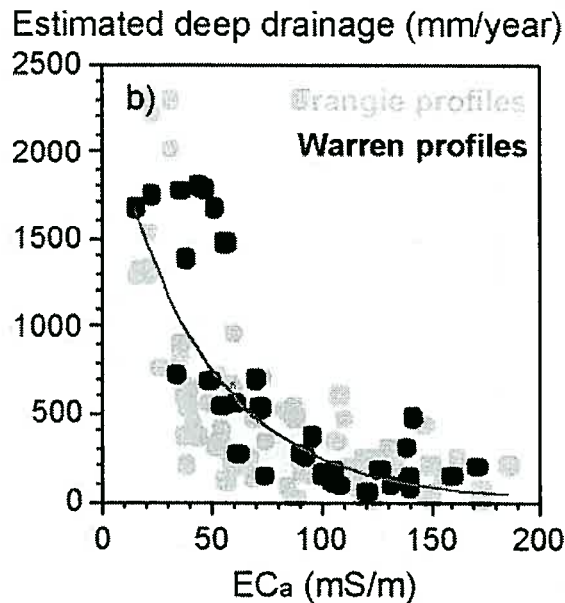


Fig. 6: Relationship between EM38 signal data (mS/m) in the vertical dipole (EM38-v) mode versus estimated deep drainage (*DD*-mm/year) if 1,800 mm/year of irrigation water (*I*) was applied and 494 mm/year of mean annual rainfall (*R*) assumed in soil profiles collected in Warren (dark shade) and Trangie (light shade) districts of the lower Macquarie valley.

It is evident that the curve (exponential) does not fit the data exactly, however. As such we would expect some errors in estimations of *DD* at EM survey sites using this relationship. Nevertheless a 4-parameter exponential decay model can be fitted to the data. The equation derived is as follows: $2,532 \times e^{(-0.0294 \times EM38-v)} + 120.7 \times e^{(0.0006 \times EM38-v)}$, so that an EM38-v value can be substituted to estimate *DD* at the site where the measurement was taken. From a practical point of view and as a first approximation this equation can be used to estimate *DD* risk in an EM survey: possibly highlighting where further soil investigations would be appropriate. It is also worth noting that the relationship between EC_a and *DD* is equivalent to that reported by Beecher et al. (2002), who assessed groundwater recharge rate beneath irrigated rice using an EM31.

Relationship between EC_a (EM34) and average clay (%) and salinity (dS/m)

Figure 7a shows the plot of EC_a (as measured with the EM34 at 10 m coil spacing) versus average (0-7 m) clay content (%) at each of the sampling sites in the Trangie and Warren districts. The regression relationships were similar in both areas (i.e. average Trangie clay content = $23.74 + 0.19 \times EC_a$ and Warren clay content = $26.25 + 0.20 \times EC_a$). The low values of EC_a (i.e. < 50 mS/m) represent profiles with average clay content of 30-35%. These equations were used to convert EM34 survey data at 10 m coil spacing into values of average clay content to a depth of 7 m. The data was interpolated onto a 75 m grid. The residuals of these equations of the line were similarly interpolated onto the same 75 m grid. The two values were added to produce the maps shown in Figure 10 of average clay content. This was the approach used in estimating average salinity to a depth of 10 m using the EM34 data at 20 m coil spacing (EM34-20). The regression relationships were slightly different (i.e. Warren salt content = $-1.71 + 0.05 \times EM34-20$ and average Trangie salt content = $-0.20 + 0.03 \times EM34-20$).

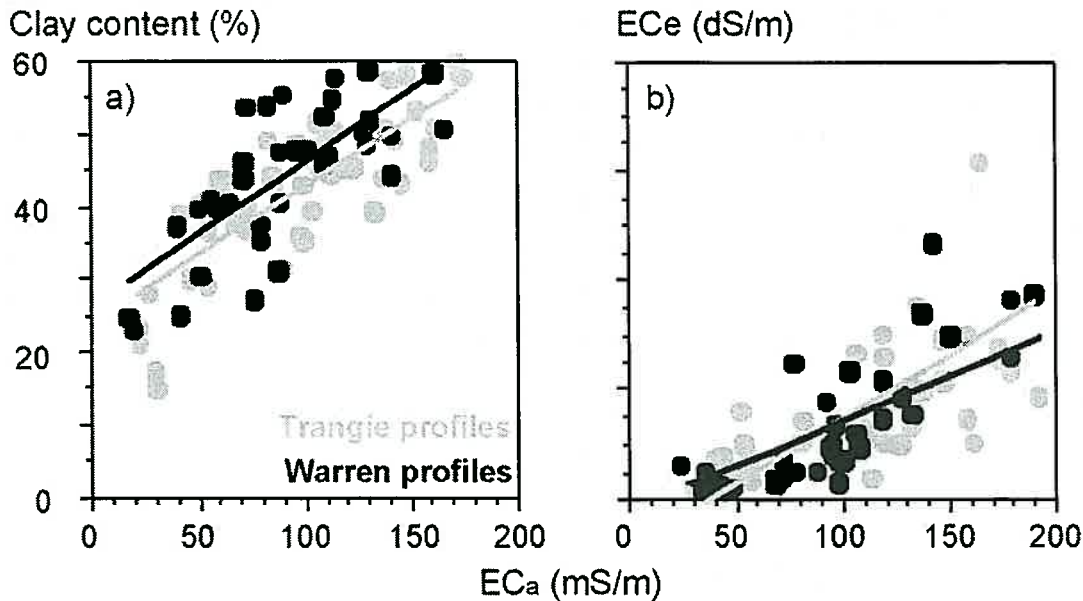


Fig. 7: Relationship between; a) EM34 signal data (mS/m) in the horizontal dipole mode and 10 m spacing (EM34-10) versus average clay content to 7 m (%), and b) EM34 signal data (mS/m) in the horizontal dipole mode and 20 m spacing (EM34-20) versus average salt content (EC_e-dS/m) to 10 m in the Warren (dark shade) and Trangie (light shade) districts of the lower Macquarie valley.

Maps of conditional probability (deep drainage risk)

In order to produce a map of where *DD* would be high (i.e. *DD* risk maps) the EM38-v measurements made in the Warren (564) and Trangie (755) districts, were converted into values of *DD* using the calibration equation (i.e. $DD = 2,532 \times e^{(-0.0294 \times EM38-v)} + 120.7 \times e^{(0.0006 \times EM38-v)}$) derived from the data shown in Figure 7. This gave *DD* estimates that ranged from as low as 3.5 mm/year to highs of 1,780 and 2,062 mm/year in the Warren and Trangie districts, respectively. This suggests that of the 2,294 mm/year applied (i.e. $I = 1,800$ and $R = 494$ mm/year) over 78 and 90 % of the water would be lost beneath a water reservoir located at these sites. Because these values are estimates derived, in the first instance from the SaLF model and secondly from EM38-v data collected under various moisture regimes (i.e. from dryland and irrigated fields) there is some uncertainty in the estimated *DD* value. Where there is such uncertainty a critical value can be selected instead, which indicates a level where *DD* may be problematic.

In the Trangie district EM38-v readings are generally less than 100 mS/m adjacent to a water reservoir (Easting 613000, Northing 6560000) where a shallow water table and soil salinisation was first reported in the early 1980's. On reviewing Figure 7 it is evident that 100 mS/m equates to a *DD* value of around 200 mm/year. Considering the fact that anecdotal evidence suggests losses are occurring from this particular reservoir, this value was used as the critical value to map. The estimated *DD* data was then transformed into values of 0 and 1. That is, if the estimated *DD* did not exceed 200 mm/year a value of 0 was assigned. Conversely, if estimated *DD* was equal to or exceeded 200 mm/year it was assigned a value of 1.

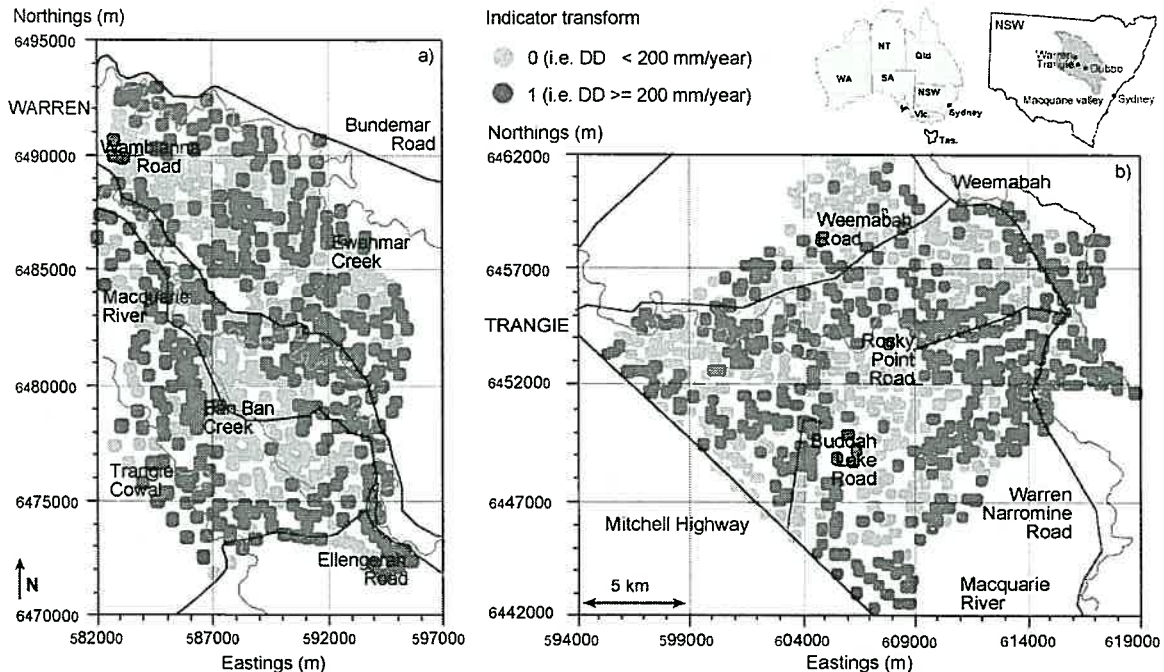


Fig. 8: Location of EM34/38 survey positions where deep drainage (*DD*) is expected to exceed critical cut-off value of 200 mm/year (dark shade) if 1,800 mm/year of irrigation water (*I*) was applied and 494 mm/year of mean annual rainfall (*R*) assumed in (a) Warren and (b) Trangie districts of the lower Macquarie valley.

Figure 8 shows a plot of where *DD* does (dark shade) and does not (light shade) exceed the critical value of 200 mm/year if 1,800 mm/year of irrigation water (*I*) was applied and 494 mm/year of mean annual rainfall (*R*) assumed. With respect to where *DD* would be exceeded, approximately 53 and 51 % of the EM38-v measurement sites meet this criteria in the Warren and Trangie districts, respectively.

In order to produce a map of the conditional probability (*CP*-or risk) that *DD* would exceed 200m mm/year at sites where EM38-v measurements were not made, we interpolated this data (i.e. 0 and 1) onto a grid of 150 m. The results are shown in Figure 9. The white areas indicate where the risk is low (i.e. $CP < 0.5$) and where *DD* is least expected to be greater than 200 mm/year. As such these areas indicate locations in the Warren and Trangie districts where the most suitable areas to locate a supply channel and/or shallow earthen water reservoirs.

In the Warren district the largest contiguous area of low risk is located in the central southern part between the Macquarie River and Trangie Cowl. In the Trangie district low risk areas include the central northern and southern parts. Conversely, the dark shaded areas indicate where *DD* is most likely to exceed 200 mm/year and where the risk (i.e. $CP > 0.9$) is highest. With respect to the water reservoir, where salinisation was first noted in the Trangie district, the results of *DD* risk is consistent with anecdotal evidence and the experience of management at this site. It should be noted that this reservoir is no longer used to store water long-term and is only used for collecting water from heavy rainfall events. This has mitigated the problem in most seasons, although in very wet years some areas are still affected.

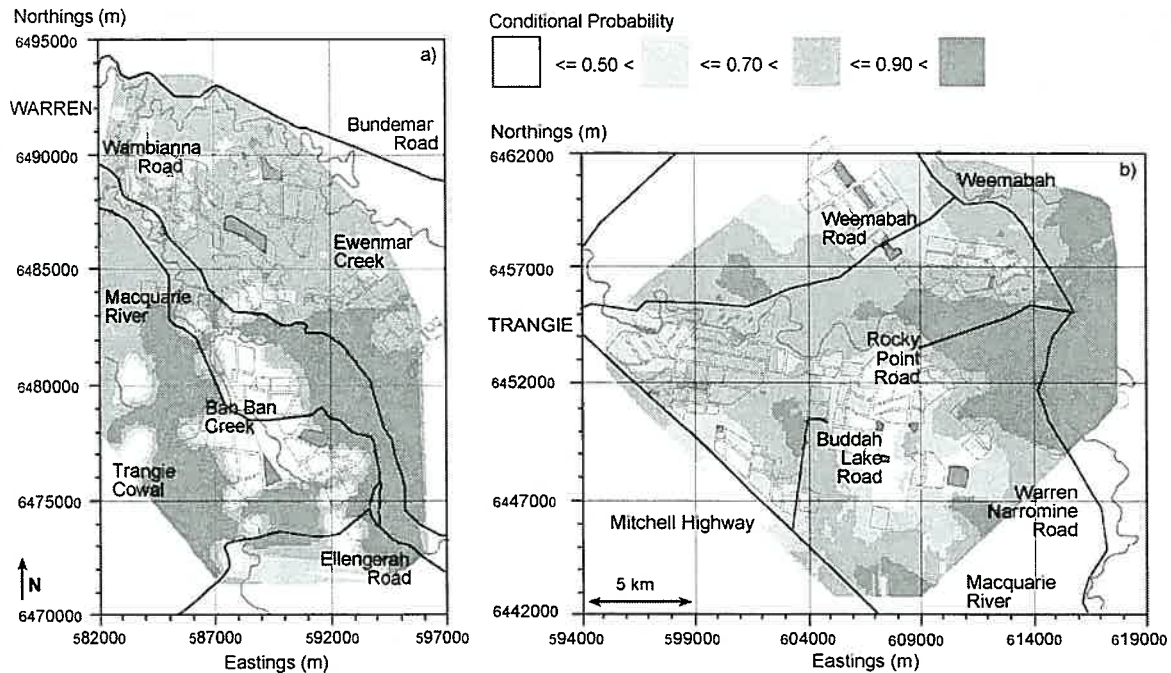


Fig. 9. Map of conditional probability (CP) that soil at a particular site will exceed an estimated deep drainage (*DD*) value of 200 mm/year if 1,800 mm/year of irrigation water (*I*) was applied and 494 mm/year of mean annual rainfall (*R*) assumed in (a) Warren and (b) Trangie districts of the lower Macquarie valley.

It is worth noting that areas where *DD* risk is highest may explain why certain landholdings, (e.g. south of Rocky Point Road and adjacent to the Macquarie River in the Trangie district), were never developed for flood-irrigated cotton production. The risk map, shown in Figure 9b, also sheds light on the issue of water use efficiency. For example, south Rocky Point Road, some of the fields are potentially of high *DD* risk (i.e. $CP > 0.9$). However, two of the fields located in the high-risk zone were developed to apply water using center pivots, hence maximising water use efficiency. In comparison, a larger portion of the Warren district falls within the category of highest risk (i.e. $CP > 0.9$). However, as with the Trangie district most of the irrigated fields appear to be located in areas where *DD* risk is lowest. Where this is not the case, field sizes are smaller than those located in other parts of the district and hence water use efficiency issues were considered during development.

The high-risk zones shown are also consistent with known areas of leakage, from supply channels and water reservoirs, where waterlogged and saline soil conditions have occurred. The best example of this in the Trangie district is adjacent to Rocky Point Road, where a major supply channel has produced these adverse conditions in the past. However, and in recognition of these problems, management strategies were implemented to minimize *DD* losses and hence groundwater accretion. For example, the supply channels in this part of the farm are only used during the irrigation (summer) season. In addition, saltbush has also been planted in strips parallel with the supply channel in order to use water that permeates laterally from the channel and hence prevent water logging and soil salinisation of the adjacent fields.

In the Warren district it is also evident that most of the area has a conditional probability exceeding 0.7. Where this is not the case is the area either side of Ban Ban Creek. In this area isolated point source salinisation has been problematic. As a consequence the EM values recorded here were the highest and influenced by the saline soil conditions. As a result the relationship established between EC_a (EM38v) and estimated DD (mm/year) may not valid in this area, because most of the sites used to establish the relationship were not affected by saline conditions. It is recommended that further work be carried out to ascertain the DD risk in this area using an alternate approach.

Maps of average clay content and stored salt

Figure 10 shows the spatial distribution of average clay content (0-7 m). The white and lightest grey shaded areas indicate where the average clay content is less than 30 and 40 %, respectively. Predominantly these areas coincide with the Trangie Cowl and Macquarie River in both areas as well as the meander plain of the Old Alluvium Pedoderm in the northern part of the Warren district and southeast of Trangie. It is evident from these figures that the Warren district is on average and to a depth of 7.0 m clayier in nature than Trangie and that for the most part the earthen water reservoirs have been constructed in areas where average clay content is greater than 40 %. It is however worth noting the island of higher clay content located on the Trangie Cowl south of Weemabah in the Trangie district as well as the area either side of Ban Ban Creek in the central and southern part of the Warren district.

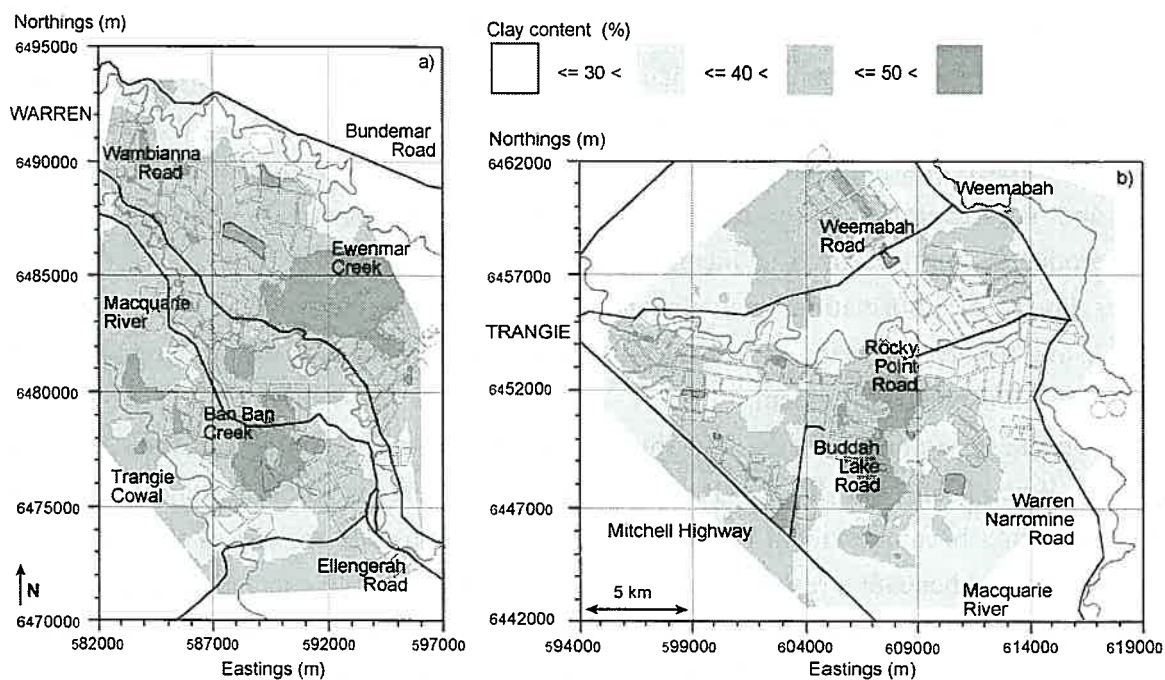


Fig. 10. Map of predicted average clay content (%) to 7 m in a) Warren and b) Trangie study areas.

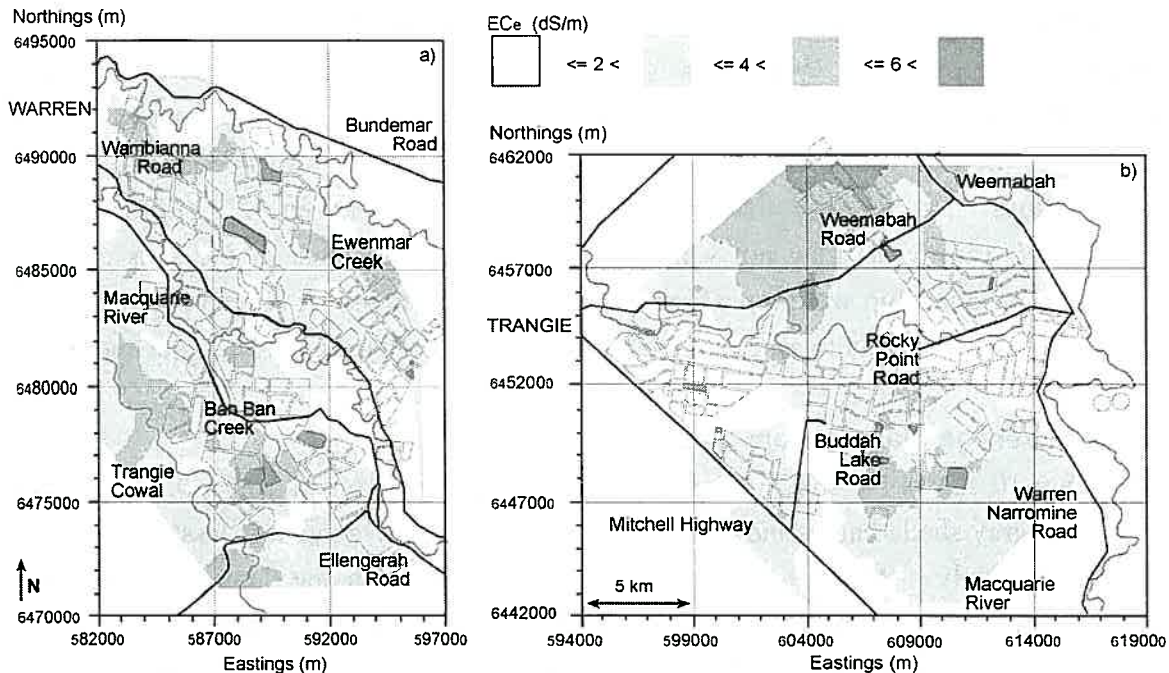


Fig. 11. Map of predicted average EC_e (dS/m) to 7 m in a) Warren and b) Trangie study areas.

Conversely, the areas of higher average clay content also contain the largest stores of salt as indicated in Figure 11. It shows the spatial distribution of average salt to a depth of 10 m. In the area southeast of Trangie this is particularly evident in the central northern and southern parts where average salinity is greater than 4 dS/m (i.e. darker grey shaded areas). Southeast of Warren the largest concentration of salt is evident south of Ewenmar Creek and associated with the Trangie Cowal Pedoderm. This is particular the case adjacent to one of the major storages where isolated salinity is evident.

Predicting salinisation

Soil salinisation in irrigated agricultural systems can arise as a result of poor water use efficiency. In the Trangie district it is thought that this arises because of excessive *DD* from water reservoirs and supply channels, which lead to the creation of perched water tables and mobilization of stored salts into the root zone. In order to ascertain whether the maps produced could be used to identify where salinisation might occur we queried the various layers of information generated (i.e. *DD* risk map, etc.). The first step was intuitive and involved looking at the root- and vadose-zone attributes where perched water tables and salinisation are evident.

The best example of this is in the Trangie district near a small reservoir located between Weemabah and Rocky Point Roads and where isolated instances of soil salinisation first became evident in the early 1980's. At this site the risk (i.e. *CP*) of *DD* exceeding 200 m beneath a reservoir was between 0.7 and 0.9. We considered a risk of 0.5 for our query of this data layer because a nearby reservoir also has some minor leakage ($CP > 0.5$). The value considered critical in terms of average clay content and salt store were 38 % and 2.5 dS/m. That is, if the average clay content to a depth of 7 m was > 38

%, we surmised this might cause impeded drainage and hence create a perched water table. Similarly, where $EC_e > 2.5$ dS/m sufficient salts were present in the profile (and above the perched layer) to cause salinisation of the root zone. The dark grey shaded areas in the map shown in Figure 12 indicate where the following conditions have been met:

- a) *DD* risk is greater than 0.5 when considering location of reservoirs
- b) Average clay content > 38 %
- c) Average salt store > 2.5 dS/m.

The maps indicate where soil salinisation may occur, based on the above criteria, if a reservoir is placed in the Warren and Trangie districts. In the Trangie district the results achieved are consistent with the water reservoir where the criteria were developed. This is between Weemabah and Rocky Point Roads. The results are validated somewhat by the problems of salinisation in fields northwest of the leaking storage. In these fields losses from irrigation head ditches or supply channels may be the cause of the deep draining water. In the Warren district the results are similarly consistent with minor point source salinisation. This is the case with respect to one of the reservoirs in the southern part of the district. The map however, was not consistent with the salinisation, which is evident to the west of one of these reservoirs. As we stated earlier this is probably due to the fact that because the EM38-bv instrument is influenced by the higher salinity rather than the low clay content and high deep drainage as suggested in Figure 6. The result is similarly consistent with and validated by the isolated point source salinisation associated with a water reservoir in the central part of the Warren district. The maps therefore can be used as a guide to assist with decision-making. However, caution is required because the maps were developed from EM information spaced 500 m apart.

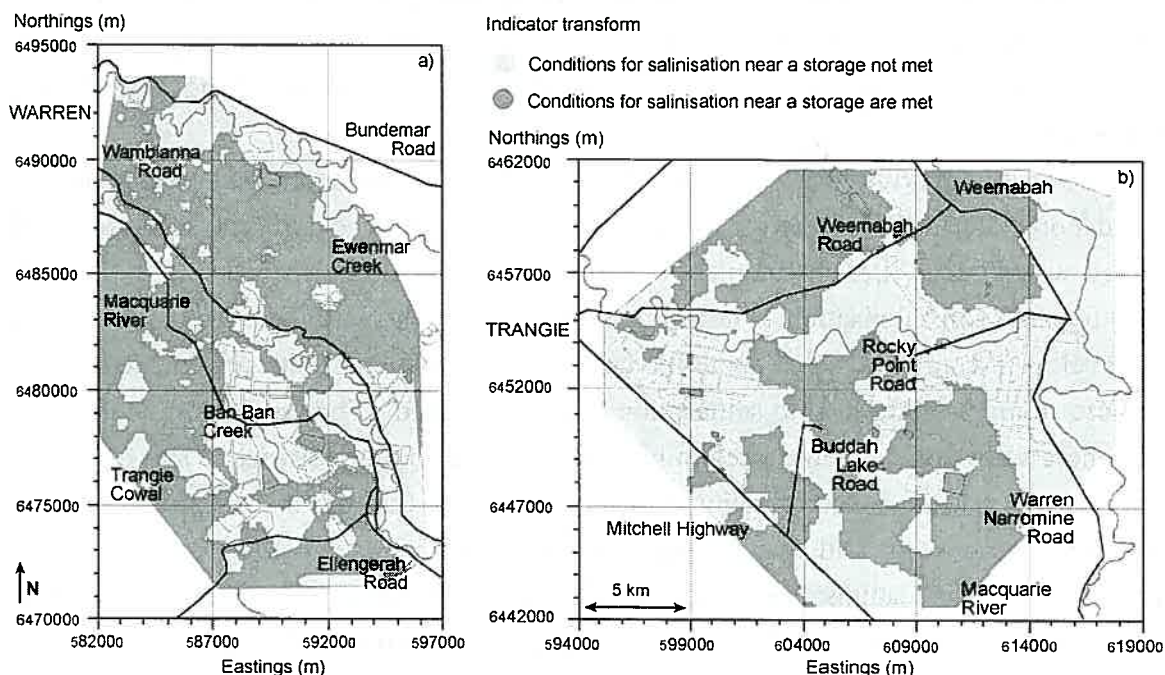


Fig. 12. Map of predicted average EC_e (dS/m) to 7 m in a) Warren and b) Trangie study areas.

Conclusions

The maps of conditional probability and associated conclusions drawn from these require some caution. This is because the estimates are based on a relationship established between a salt-water balance model (SaLF) and an EM38 instrument. The EM38 measurements were made at the height of summer in dryland and irrigated fields. Consequently, measurements were not made under uniform soil moisture conditions. This is significant in areas where EC_a is between 75 and 125 mS/m, because the 4-parameter exponential models used to establish relationships between DD (SaLF estimate) and EC_a (EM38), increases exponentially (Figure 14). In addition, errors are associated with the spatial variability of the EC_a data and the sampling interval used (i.e. 500 m).

Nevertheless, the maps of conditional probability (Figures 9), produced using indicator kriging, illustrated at the district scale areas where problems with DD are most likely to be occurring. The areas exhibiting the largest probability of excessive DD (i.e. > 50 mm/year) using the various water application volumes (i.e. $I = 1,800$ mm), corresponded to permeable soil types associated with the Trangie Cowal, Contemporary Macquarie and meander plain of Old Alluvium Pedoderms (Figure 2). As a result the methodology developed here indicates where a more strategic approach may need to be implemented at the district and field scale when considering options to improve irrigation efficiencies and water delivery southeast of Warren and Trangie. This is particularly the case with the location of head ditch and supply channels, which are currently, located in high risk areas. We suggest EM38 surveys to be carried out using Mobile EM Sensing Systems in association with the equation derived from Figure 7 to estimate deep drainage and map risk of exceeding a critical value (i.e. $DD > 200$ mm/year). In areas deemed to be at high risk, possible management options include lining channel in these areas with bentonite curtains to improve water delivery or rerouting infrastructure through areas that have lower risk. Otherwise these structures should only be used in conveying water during the irrigated season.

The spatial distribution of vadose zone properties such as average clay content (0-7 m) and stores of salt (0-10 m) were useful in identifying values consistent with presence of perched water tables (i.e. clay content > 38 %) and sufficient salt stores (i.e. $EC_e > 2.5$ dS/m) to cause soil salinisation. The production of a map where all these features occurred and developed from knowledge about the causes of salinisation at one site enabled a map of where storages might lead to salinisation being developed. The results were consistent with where salinisation has occurred in both Warren and Trangie districts. The final map also suggests that the cause of salinisation is similar and that the management practices developed to live with and manage salinisation in the Trangie district are most likely transferable to where salinisation has occurred in the Warren district. That is extension of best management practices developed in Trangie can be extended to Warren.

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