

Assessing sustainability and salinity threat from application of poor quality water in the lower Macintyre and Gwydir valleys

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Introduction

Irrigation with either moderate to highly saline and/or sodic water can create problems within the root-zone. Application of saline water for example can lead to increased salinity within the seedbed if there is insufficient leaching of the salts through the soil profile. Where there is excessive deep drainage, shallow saline water tables may be created and result in the concentration of salts within the root-zone through capillary rise. In order to determine the possible effect and long term sustainability of irrigated agricultural production in a particular area two things are necessary. The first is information about the spatial distribution of soil and water resources suitable and currently being used for irrigation. This can be collected by reconnaissance soil surveys (Odeh *et al.*, 1996) or from already existing soil and water quality information. Secondly, soil\water balance models can be used effectively to estimate soil salinity build-up and deep drainage beyond the root-zone using this information.

A number of models have previously been developed and are of potential use. Of these the steady-state leaching requirement model of the United States Salinity Laboratory (1954) requires a small number of easily measured soil properties for the calculation of leaching flux beyond the root-zone. Unfortunately, the model assumes that the soil has reached steady state whereby salts applied in the irrigation water equals salts leached in drainage water. If the salinity level in the soil is not in equilibrium the model is invalid. SODICS (Rose *et al.*, 1979), which is a transient mass balance model, is more applicable when this is the case and is suitable in providing predictions of deep drainage, particularly in slowly permeable soils that are prevalent in the irrigated cotton growing areas of northern NSW. This model however, requires soil information at two different times, that is prior to the commencement of irrigation and the present day or at the start and end of a calendar year. This information is then used for the purpose of comparison and calculation of the deep drainage using the chloride profile as an indicator.

Owing to the large area used for irrigated cotton production in the lower Macintyre and Gwydir valleys, a simpler model that requires only rudimentary soil survey data would be more appropriate. The so-called Salt and Leaching Fraction Model (ie. SaLF) was therefore developed by Shaw and Thorburn (1985) and Shaw (1988). It is based on the assumption that soil leaching or deep drainage is related to hydraulic conductivity which in turn is influenced by the amount of clay (%), clay mineralogy (Cation Exchange Capacity/Clay %) and exchangeable sodium percentage (ESP). Once these soil properties and water quality and quantity parameters have been determined and entered into the empirically based model,

estimates of leaching fraction (LF) deep drainage (DD in mm/year) and average root zone EC_e at steady-state are predicted. A small number of water quality parameters, such as EC_w , depth of irrigation water applied and annual rainfall, as well as the crop being grown is also required by the model.

In the following paper we show how the latest version of this model, Sodium-SaLF, and data generated from a reconnaissance broad-scale soil survey are used to assess the current status of soil salinity and potential threat due to the application of poor water quality in the lower Gwydir and Macintyre valleys of northern NSW.

Materials and Methods

Previously soil samples were collected and analysed for a small number of rudimentary soil properties including soil pH, $EC_{1.5}$, chloride, topsoil organic matter, bicarbonate phosphorus and particle size analysis (ie. determination of clay, silt and sand fractions) in the lower Macintyre and Gwydir valleys, as illustrated in Figure 1. In total 120 soil sampling locations were selected and visited in the lower Macintyre valley, predominantly located in irrigated cotton growing fields from Goondiwindi in the east of the valley to Mungindi in the west. In the lower Gwydir valley a slightly larger number of samples has been collected to date (ie. 153) near the township of Moree in the east, Garah and Telleregah and around Collarenebri in the west where a small number of additional samples are still to be collected. At each site six soil samples were collected including: 0-0.1, 0.1-0.2, 0.3-0.4, 0.6-0.7, 1.1-1.2 and 1.9-2.0 m (Odeh, pers. comm.).

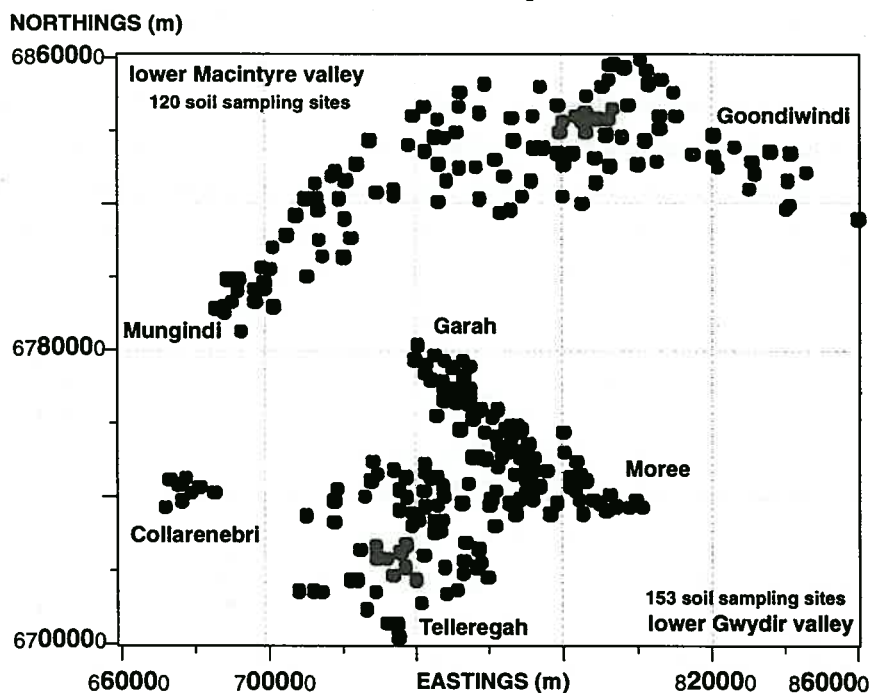


Figure 1. Map of soil sampling sites located in the lower Macintyre and Gwydir valleys.

In addition to these soil properties and as required by the Sodium-SaLF model we determined the cation exchange capacity (CEC) of the soil using the method of Tucker (1974) and Holmgren *et al.*, (1977). This was done in four of the five root-zone depths (ie. not including 0.1-0.2 m sample). In addition, a small reconnaissance water sampling survey was also conducted in the lower Gwydir valley to assess the current water quality available for

irrigation. This involved collecting water samples from most of the water courses which supply the irrigated cotton farms of the valley and included the major rivers of the Gwydir, Mehi and Barwon Rivers as well as Carole, Moomin and Greenbah Creeks. The samples were collected usually at points in each water course where easy access could be obtained to the centre of the stream, the samples collected using a custom built water sampling vessel (see Figure 2a). A small and relatively inexpensive Magellan NavPro5000 GPS was used to provide positional information at each site and is shown in Figure 2b mounted in a vehicle.

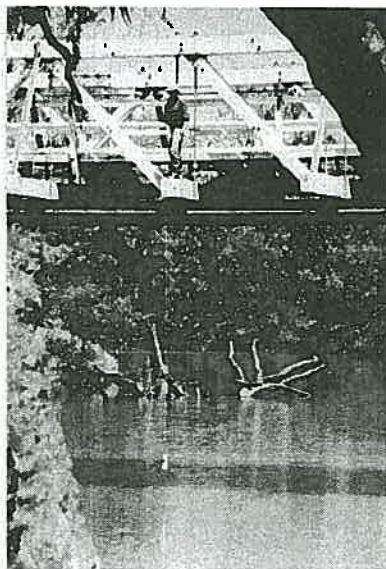


Figure 2a. Water sampling in the lower Namoi valley.



Figure 2b. Magellan NavPro5000 GPS.

Results and discussion

In total 21 water sampling locations were visited on either the 6th or 7th of November 1997, and are illustrated in Figure 3. Table 1, shows the various water quality attributes determined including chloride, sodium, electrical conductivity of the water (EC_w) and Sodium Adsorption Ratio (SAR) for just over half of these locations. The table also lists the identification number of each sample shown in Figure 3.

The suitability of water for irrigation is dependent on crop, climate, soil, method of irrigation and water quality (Rhoades *et al.*, 1992). Despite this a general statement can be made about the data presented in Table 1. The first is that average EC_w was 0.435 dS/m and is considered non-saline (ie. <0.7 dS/m) and well within acceptable limits for irrigation. Only one water sample, collected from Greenbah Creek, contained twice this amount of salt but is still suitable as irrigation water (ie. 0.7-2.0 dS/m). Interestingly, this water sample also contained slightly higher amounts of sodium and chloride which in excessive concentrations can lead to reduced yields due to ion toxicity. Apart from this sample however the samples collected in the Gwydir valley fell beneath the critical values of <3 mmol_c/l for sodium and <3 meq/l for chloride. The data also shows no significant increase in water salinity along the Mehi River which runs along the entire length of the lower Gwydir valley and suggests there is no salt loading caused by high water tables beneath irrigated cotton farms.

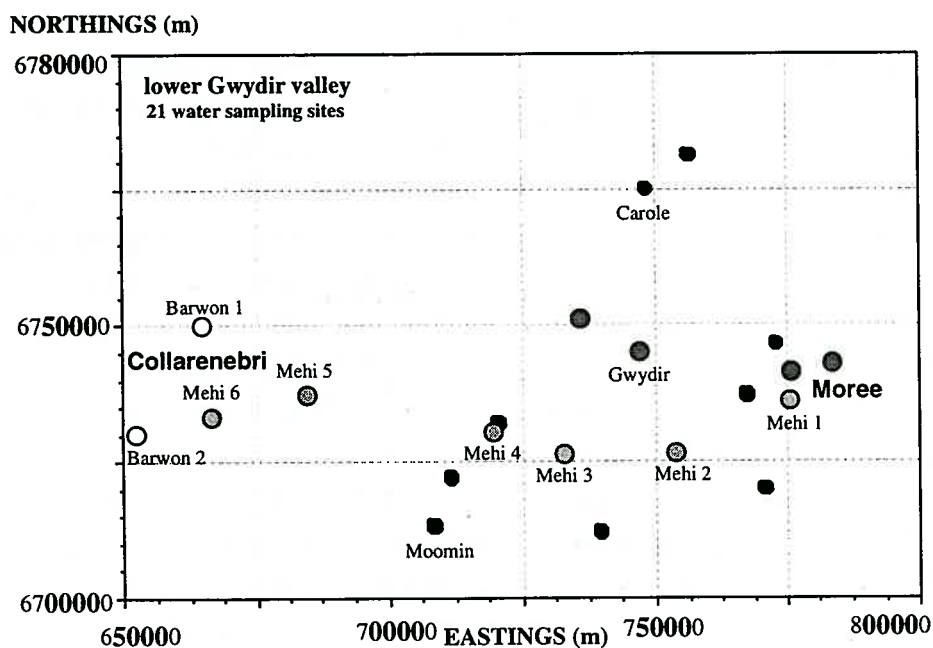
The reason for the discrepancies apparent with the Greenbah sample is possibly due to the fact that at time of sampling, water was not flowing in the creek and as a result salts have been concentrated. Follow up water sampling will be carried out to confirm this.

Table 1. Water quality attributes of some samples collected in the lower Gwydir valley.

Location	Water Course	I.D. No.	Easting	Northing	Chloride (meq/l)	EC _w (dS/m)	Na ⁺ (mmol/l)	SAR
Moree	Mehi River	Mehi 1	775500	6736500	0.57	0.44	1.13	0.96
Combadello Bridge	Mehi River	Mehi 2	753900	6726700	0.57	0.42	1.19	1.04
Hickey Bridge	Mehi River	Mehi 3	733000	6726500	0.55	0.47	1.34	1.11
Mallowa	Mehi River	Mehi 4	719800	6731000	0.63	0.51	1.44	1.15
Mogli Mogli	Mehi River	Mehi 5	684377	6737451	0.61	0.48	1.46	1.22
Collarenebri	Mehi River,	Mehi 6	666952	6733721	0.52	0.44	1.32	1.18
Mogil Weir	Barwon River	Barwon 1	664720	6749902	0.48	0.31	1.06	1.19
Rocky Ford Bridge	Barwon River	Barwon 2	766400	6639500	0.35	0.22	0.87	1.22
Greenbah Creek	Greenbah Creek	Greenbah	767500	6737500	2.07	0.85	5.93	5.94
Minnaminane	Moomin Creek	Moomin	739600	6712300	0.49	0.38	1.01	0.94
Mopriana	Carole Creek	Carole	748217	6775235	0.48	0.41	1.26	1.14
Wearmatong	Gwydir River	Gwydir	746987	6745164	0.37	0.33	0.92	0.92

In addition to total salt concentration, the level of sodium relative to divalent cations can adversely affect soil properties for irrigation and cropping. At high levels of sodium clay minerals tend to swell and disperse and aggregates tend to slake, especially under conditions of low salt concentration and high pH. As a result the permeability of the soil is reduced and the surface becomes more encrusted and compacted. Sodidity is defined as the proportion of adsorbed exchangeable sodium relative to the cation exchange capacity rather than the absolute amount of exchangeable sodium known as the exchangeable sodium percentage (ESP). Because ESP and the sodium adsorption ratio of the saturation extract, where SAR is:

$$SAR = Na / \sqrt{(Ca + Mg) / 2}, \text{ (ie. solute concentrations are in (mmol}_e\text{/l))}, \text{ are closely related, SAR is used as a substitute for ESP and as an index of the sodium hazard of soil and waters. Water samples which have an SAR value of less than 0.3 are considered non-sodic of which most of the samples collected in the valley are below. Again, the Greenbah Creek sample is considered to be slightly sodic (ie } 3 < SAR < 6) \text{ but despite the slightly higher values of salinity and sodicity of water from this stream would still be reasonably well suited for the purposes of irrigation although small applications of gypsum may be required to maintain soil permeability and tilth.}$$

**Figure 3.** Location of the 21 water sampling locations in the lower Gwydir valley.

With the soil and water quality information generated, the Sodium-SaLF model was used to determine the current status of soil salinity within the root-zone and sustainability with respect to an average water salinity of 0.44 dS/m (ie Gwydir valley). Each of the 273 sites were entered into the program and included the attributes of clay content and cation exchange capacity at four depths (ie. 0-0.1, 0.2-0.3, 0.6-0.7 and 1.1-1.2 m) and exchangeable sodium percentage at a depth of 1.2 m. We also assumed that at each site the average annual rainfall was 584 mm and that 600 mm of irrigation water is applied annually. In order to determine the effects of applying progressively more saline water with respect to increased soil salinity and deep drainage we also carried out simulations of adding water with EC values of 1.4 (slightly saline), 4.0 (moderately saline) and 9.0 dS/m (moderate-high salinity).

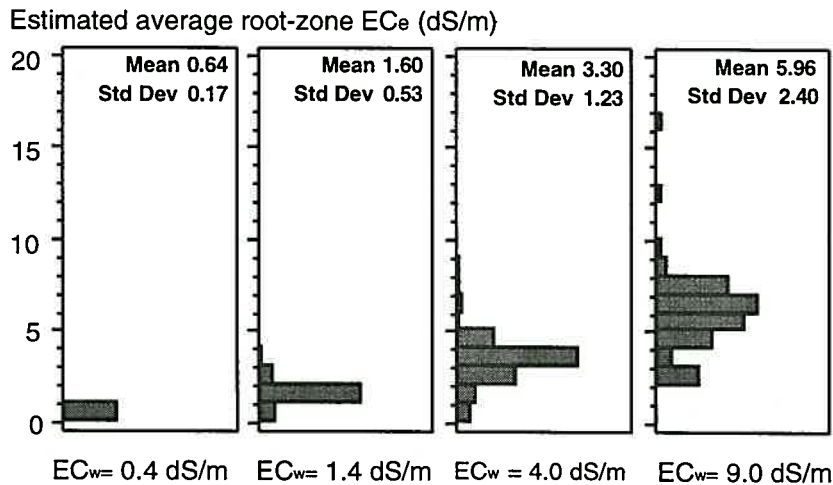


Figure 4. Histograms of estimated average root-zone salinity (dS/m) at steady state using SaLF and various EC_w water quality values.

The results of the simulations generated by Sodium-SaLF are illustrated in Figures 4 and 7, respectively, the estimated average root-zone EC_e (dS/m) and deep drainage (mm/year) occurring at steady state. The simulation using the current average water quality (ie. EC_w 0.44 dS/m) suggests that at present this water quality is sustainable for irrigated cotton production since average soil salinity across the valley would be 0.64 dS/m at steady state. This value is well below an EC_e of 4.0 dS/m which is the critical value required for susceptible crops to be affected (eg. beans) and well below the value to affect wheat (ie. 6.0 dS/m) and cotton (ie 7.7 dS/m). This is similarly the case if the slightly saline water of EC_w 1.4 were applied since average soil salinity EC_e is still only 1.6 dS/m. If EC_w of 4.0 was applied, some crop management could be necessary (ie. selection of more tolerant crops), since the level of salinity within the root-zone, at steady state, and on average (ie. 3.3 dS/m) in the areas is approaching a level where sensitive crops may show reductions in yields of perhaps 5 %.

If on the other hand a water of electrical conductivity of 9.0 dS/m was applied, susceptible crops could possibly still be grown with reasonable success if suitable crop, soil (eg. seed-bed design) and/or irrigation management (method of application) were developed and depending on the prevailing conditions. In most cases and most soil types of a heavy clay nature, irrigated cotton production should theoretically be uninhibited by an average EC_e of 5.96 dS/m, although and with respect to rotation crops such as wheat, these levels may cause some reduction in yield.

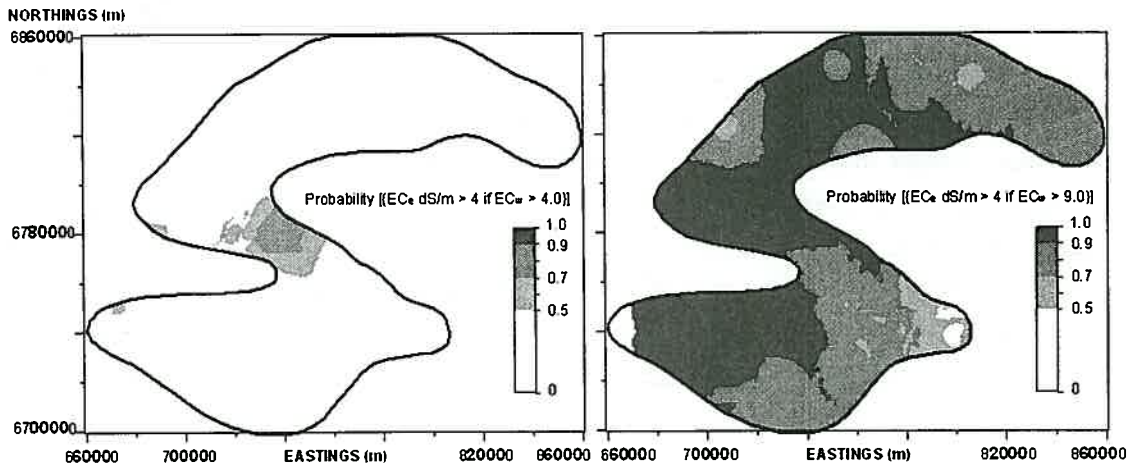


Figure 5. Indicator kriged map of average root-zone $EC_e > 4$: **a)** when water quality of $EC_w = 4$ dS/m is applied and **b)** when water quality of $EC_w = 9$ dS/m is applied.

The soil types or areas at risk if these water qualities were the only ones available (ie. EC_w of 4 or 9 dS/m) for irrigation can be shown using a geostatistical interpolation method known as indicator kriging. Triantafyllis and McBratney (1986) previously showed how this method can be used to prepare probability maps. For example, if average soil salinity exceeds 4.0 dS/m we can anticipate that there will be a high probability (ie. 1) that some loss in production will occur if sensitive crops are planted. The probability maps illustrated in Figures 5a and b show the areas where soil salinity could be expected to be greater than this critical level in the lower Macintyre and Gwydir valley, if EC_w of 4.0 and 9.0 dS/m was applied, respectively.

Figure 5a shows that only the area around Garah may have levels of salinity approaching or exceeding 4.0 dS/m and hence yield would most probably be unaffected with the use of moderately saline water of EC_w 4.0 dS/m. Figure 5b, on the other hand, indicates a rather different result and suggests that at steady state, the application of EC_w 9.0 dS/m would most likely result in approximately 30 % of the land (ie. dark shaded area with probability of 0.9-1) irrigated with this water quality would have an average soil salinity greater than 4.0 dS/m and result in some yield reduction if no soil or water management were carried out.

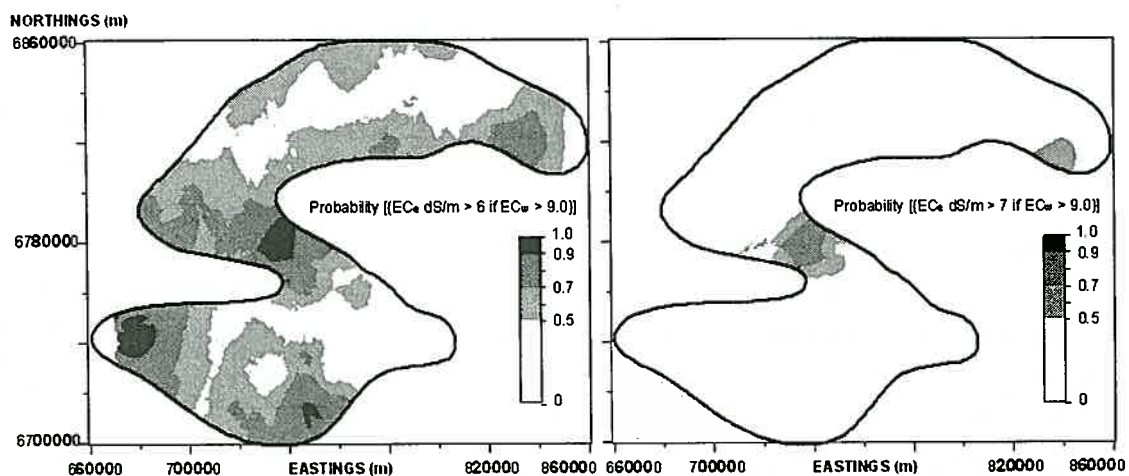


Figure 6. Indicator kriged map of: **a)** average root-zone $EC_e > 6$, and; **b)** average root-zone $EC_e > 7.7$ when water quality of $EC_w = 9$ dS/m is applied

Figures 6a and 6b suggest that unlike the more sensitive crops, the moderately tolerant wheat and cotton crops would most likely be not as severely restricted by the salinity levels in the soil when the moderate to high salinity water of EC_w 9.0 dS/m is used. Again the area around Garah is of possible concern, but what is more clearly apparent is the areas least likely to be affected as illustrated by the white areas in Figure 6a (ie. probability < 0.5). The reason for this would appear to be that the soil is slightly sandier in nature, due to the closer proximity of these areas to the current Macintyre and Gwydir River floodplains and prior stream channels. As a result fewer soluble salts will be stored in the profile. However, with the increased electrolyte concentrations soil permeability is also improved and would therefore lead to increased amounts of deep drainage.

This is clearly illustrated in Figure 7 which shows that using progressively more saline water, deep drainage also steadily increases. For the most part, excessive deep drainage is limited to only a few soil profiles, however, it is of concern in some profiles since the leaching fraction is around 10-25 % if a moderately to moderately high salinity water were applied. This has implications for the creation of not only rising water tables and water logging but also of soil salinity since many of these deep draining salts may resurface.

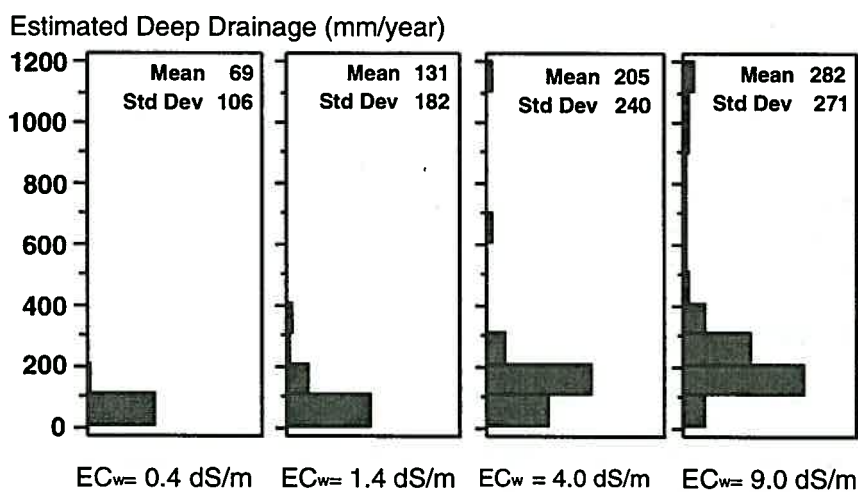


Figure 7. Histograms of estimated deep drainage (mm/year) at steady state using SaLF and various EC_w water quality values.

Conclusions

It must be remembered that the work described here is based on simulations generated from a computer model and soil samples collected on an approximate 2.5-5 km grid in the lower Macintyre and Gwydir valleys and include profiles not currently irrigated. Nevertheless, the results suggest that, using the current water quality available for irrigated cotton production should not result in increased levels of soil salinity in the root-zone. Further, and considering the worst case scenario of using moderate to high salinity water EC_w of 9.0dS/m, the levels of soil salinity which will result could still be sustainable using either or a combination of suitable crop, soil or irrigation management practices. What may be of more concern is the excessive deep drainage that may result using the highly saline water quality, as simulated here, and the potential for this to lead to the creation of shallow saline water-tables.

Future work

The work described here will be carried out in the lower and upper Namoi valleys where soil samples are currently being collected and the necessary soil information is being generated by staff from this NHT project. Simulations using various combinations of sodic and saline water quality will also be carried out using Sodium-SaLF. Other work that may need attention is what upstream factors could cause the salinity of water to increase to such levels as those simulated here. The soil CEC data generated here along with the clay data generated by CRC project 1.5.1 (Quantitative assessment of soil-Dr Inakwu Odeh, CRC-The University of Sydney) will be incorporated into a newer version of Sodium-SaLF as part of CRC project 1.5.4 (Quantitative water quality guidelines-Mr Ian Gordon, Department of Natural Resources).

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