Determining Depth to Watertable for the Eastern Murray-Darling Basin, Australia

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Abstract: Determining the spatial extent of shallow watertables is a critical input into catchment scale salinity modelling and catchment planning activities. This paper describes work undertaken by the New South Wales Government as part of the Dryland Salinity Theme of the National Land and Water Resources Audit. A number of techniques to spatially generalise watertable maps from groundwater bore data were evaluated, but were found to be scientifically or statistically unacceptable, or limited by a lack of reliable data. The selected approach that evolved from this evaluation process, showed that in New South Wales, at least 180 000 ha of land have shallow watertables of less than 2m below the soil surface or are currently affected by dryland salinity. Over 90% of affected land occur in five major catchments - the Murray, Murrumbidgee, Lachlan, Macquarie and Hunter Rivers. Future predictions revealed that within the Murray-Darling Basin (MDB) alone, the area affected by 2050 is predicted to increase from the current 152 000 hectares to 1.3 million ha, a greater than eight-fold increase. Over 90% of land currently affected by salinity is agricultural. The area affected could increase eight-fold over the next 50 years. The length of roads and railways affected by salinity is likely to increase five-fold over the next 50 years. Urban salinity, already an issue in many towns in New South Wales, will worsen, with areas affected increasing from the current 954 ha to 3 646 ha by 2050. A key outcome from this study was the need to improve the methodology so that more reliable depth to watertable maps can be determined. Topographical attributes other than slope and elevation need be assessed as an indicator of shallow watertables to improve current and future extent maps.

Keywords: Salinity; Watertable mapping; Hydro-Geomorphic Unit.

1. INTRODUCTION

Determining the spatial extent of shallow watertables is a critical input into catchment scale salinity modelling and catchment planning activities. The quantification of areas affected by shallow watertables provides us with current salinity hazard areas, and when coupled with rates of watertable rise, future predictions of watertable depths and associated groundwater discharge and salt export can be undertaken.

Estimates of current and future watertable depths underpin many audit activities in Australia; for example, the Murray-Darling Basin Salinity Audit [Murray-Darling Basin Ministerial Council, 1999] and the National Land and Water Resources Audit [National Land and Water Resources Audit, 2001]. As part of the New South Wales Contribution to the Murray-Darling Basin Salinity Audit, crude estimates on areas affected by shallow watertables were made from the proportion of groundwater bores with measured depth to watertable less than 2m. During this activity, a 9 second Digital Elevation Model (DEM) was assessed to apply a topographical limitation to the spatial extent of shallow watertables. However, the resolution of this DEM (approximately 270m) was found to be too coarse for this application. As part of the National Land and Water Resources Audit, the recently available 25m DEM was assessed to apply a topographical limitation to the extent of shallow watertables. This paper describes the work undertaken by the NSW Government as part of the Dryland Salinity

Theme of the National Land and Water Resources Audit.

2. METHODOLOGY

2.1 Available Data

Three datasets, *viz*, production bore data, monitored bore data and occurrences of saline outbreaks from air photo interpretation were used to construct depth to watertable maps.

Groundwater production bore data is collected by the driller and is forwarded by the landholder for inclusion into Departmental databases. A major problem with production bore data is the segregation of watertable data from aquifer standing water level. In many cases, drillers when drilling a private stock and domestic water supply bore will drill through the watertable looking for the largest supply possible for their client and consequently, water is only logged when a useable quantity and/or quality water is encountered. Also, it was imperative that water levels from confined aquifer conditions are removed thus removing those data where a false indication of watertable may have been represented. Only production bore data from 1980 to 2000 were considered to represent current conditions; a total of 7036 bores. The location of each bore is presented in Figure 1. A range of data quality procedures was applied to remove obvious spurious data points. This reduced the number of suitable bores to 5943.

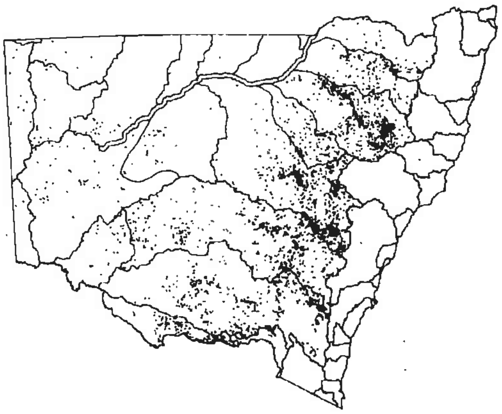

Figure 1. Locations of production bores used in the analysis.

A network of 1273 monitored bores is also available for New South Wales. However, the data collated included a substantial number of bores with only two or three measurements of watertable over a 10 year period.

For many parts of NSW, current saline outbreaks have been mapped from aerial photography. The data collected from 1990s aerial photography has been digitised, compiled and joined into a single coverage. Although this data set represents an incomplete spatial coverage of NSW, it contains data for many areas of NSW where dryland salinity is considered a major issue.

2.2 Current Watertable Map

A number of different approaches were used in an attempt to construct a current watertable map. The underlying assumption is to spatially extrapolate the point bore data based on topography to estimate other areas of the landscape likely to have shallow watertables. These methods evaluated are briefly described below.

The first approach trialed was the Hydro-Geomorphic Unit or HGU method [Salama et al., 1996]. The HGU methodology divides an area into hydro-geomorphic units based on topography and geology. Regression equations are constructed for each HGU to relate watertable elevation to topographic factors for different geologies. Other studies have shown excellent relationships (r^2 >0.95) between watertable elevation and ground surface elevation.

The second approach trialed was spline interpolation. The ANUSPLIN interpolation package [Hutchinson, 1999] was evaluated in an attempt to produce a depth to watertable map that includes topographical effects. ANUSPLIN was selected as it has been widely used, and successfully applied to generate continental climate surfaces for Australia that included topography. ANUSPLIN also has a major advantage over other interpolation packages in that it permits the user to include other factors (e.g. elevation) as either independent variables or covariates within the interpolation procedure. Splines were constructed of the form:

$$DWT = f(\text{latitude},\text{longitude}) + C\ \text{elevation}$$

and

$$DWT = f(\text{latitude},\text{longitude},\text{Elevation})$$

The third approach trialed was kriging. Kriging routines within SURFER were used to interpolate between the known depths to watertable. This approach does not explicitly describe the interactions between watertable and topography. However, the simplicity of this approach is probably commensurate with the quantity and quality of the available production bore data. We interpolated depth to watertable directly rather than watertable elevation to avoid "filling valleys with water". Although this approach will not produce a detailed watertable map applicable at property scale, it should provide reasonable estimates at a catchment and subcatchment level. The results will be largely dependent on the spatial coverage of bores. Results should be more reliable for catchments with a larger number of bores. However, the methodology ensures that all areas identified as having shallow watertables are underpinned by measured data from one or more bores. This approach will not artificially create other areas of shallow watertables based on topography and geology. Consequently, there is a high level of confidence that all areas identified with a shallow watertable, do in fact have a shallow watertable.

A preliminary map obtained from kriging showed a large underestimation of areas affected by dryland salinity. In order to capture the best data available, the kriged watertable map was merged with the current salinity outbreak areas data obtained from air photo interpretation. For graphical display of maps, the data have been aggregated to occurrences within 1 km grid cells. The original polygon data were used for all area calculations and impact analyses.

2.3 Future Watertable Maps

In order to calculate watertable maps for 2020 and 2050, rates of watertable rise were required. Data from each of the 1273 monitored bores were analysed to estimate the average annual rate of rise (ie. m per year). Rates of rise were compiled for each groundwater flow system as defined by Coram et al. [2000] in each of the eastern Murray-Darling Basin catchments. The analysis assumed that groundwater rose linearly through time. Due to the inadequacy of available information, no attempt was made to capture more realistical groundwater flow processes as watertables rise.

2.4 Impact Analyses

An assessment of the impacts of the current and future shallow watertables on land use and infrastructure was undertaken by digitally overlaying the watertable maps with other digital data sets. Overlay techniques within ArcInfo Geographical Information System were used for all analyses. Data used, as supplied by the National Land and Water Resources Audit, were:

- infrastructure data [Australian Surveying and Land Information Group, 1997], and
- land use data [Bureau of Rural Sciences, 2000].

3. RESULTS AND DISCUSSION

3.1 Watertable Mapping Using HGUs

Previous studies using the HGU method have shown excellent relationships ($r^2 > 0.95$) between watertable height and elevation. We were able to produce similar regression equations in this study. However, when these regressions were further analysed to evaluate how well depth to watertable below the surface rather than relative watertable elevation is predicted, the predictive performance of this equations is generally exceptionally poor ($r^2 < 0.1$ for most cases). The HGU approach depends on linear regressions between the elevation of the watertable and elevation of the ground surface. That is:

$$EWT = a + b\ ELEV$$

Where

EWT is the elevation of the watertable
ELEV is the ground surface elevation

In many cases, the elevation of the watertable and elevation of the ground surface are similar. Hence, it is very likely to get an excellent statistical correlation between these two very similar sets of data. But, it is the difference between the two (i.e. depth to watertable) that is of primary concern. What may be statistically, a good predictor of elevation of the watertable may be indeed, a very poor predictor of depth to watertable.

This is illustrated in the results of the HGU model evaluation for parts of the Namoi, Macquarie and Murrumbidgee catchments in New South Wales. Figure 2 shows the relationship between watertable elevation and surface elevation for a selected HGU in the Macquarie catchment. An excellent statistical correlation was found. Results from the relationship between depth to watertable and elevation for the same HGU is presented in Figure 3. Statistically, this relationship is poor, with substantial errors in model performance. In addition, the trend in Figure 3 shows that depth to watertable decreases at higher points in the landscape; a counter intuitive result. Figure 2 shows the same mathematical trend, but it is hidden in the way in which the model is presented.

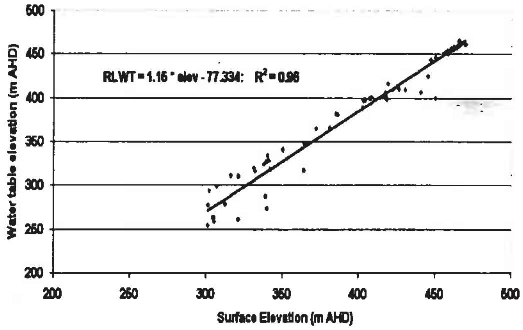

Figure 2. Relationship between watertable elevation and surface elevation for a selected HGU in the Macquarie catchment.

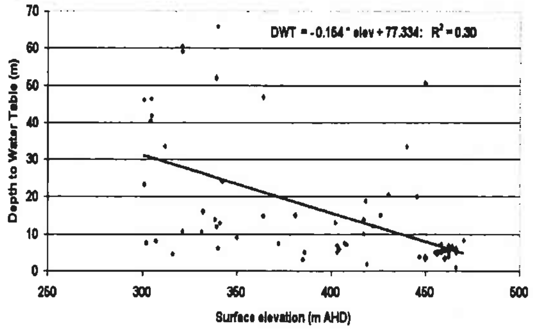

Figure 3. Relationship between depth to watertable and surface elevation for a selected HGU in the Macquarie catchment.

The HGU approach was further evaluated by investigating the effects of applying it at two different scales. HGUs were derived for the Namoi, Macquarie and Murrumbidgee catchments as a whole as well as selected subcatchments. The results summarised in Table 1, show that the calculated r^2 were generally poor regardless of the scale at which the model was applied.

From these analyses, the HGU approach was deemed inappropriate for this study.

3.2 Results from Spline Interpolation

Results from ANUSPLIN showed that there appeared to be little or no spatial coherence between depth to watertable and simple topographical attributes. Statistics of fit were so poor that they are not worth presenting here. The failure of the ANUSPLIN approach was in no way related to the methodology. It was the lack of sufficient data quality that limited its application in this study.

Table 1. Summary of the evaluation of the HGU approach for three catchments and three smaller subcatchments.

	r^2					
	Entire catchment			Local catchment		
HGU	Namoi	Macquarie	Murrumbidgee	Duncans	Talbragar	Muttama
1	0.12	0.02	0.02	n/a	n/a	n/a
2	0.31	0.14	0.01	n/a	n/a	n/a
3	0.69	0.01	0.53	n/a	n/a	n/a
4	0.01	0.30	0.03	n/a	0.07	0.02
5	0.10	0.05	0.22	n/a	0.08	0.03
6	0.00	0.00	0.01	n/a	0.82	0.07
7	0.06	0.01	0.00	1.00	0.00	0.01
8	0.01	0.01	0.01	0.01	0.00	0.01
9	0.03	0.14	0.04	0.13	n/a	n/a

3.3 Results from Kriging

The failure of the two above approaches to produce a depth to watertable map based on topography was probably due a number of factors. Firstly, an inadequate number and spatial density of production bores. Secondly, errors in the production bore data set. Thirdly, inherently poor correlations between simple topographical factors (slope and elevation) and depth to watertable. Finally, the neglect of other factors affecting watertables (e.g. vegetation).

These issues were too substantial to be overcome within the timelines of this study, so no further attempt was made to develop a technique to spatially extrapolate data according to topography. Instead a simpler approach of kriging as developed and applied.

The final current extent map presented in Figure 4 is a combination of two separate data sets. However, the method of analysis ensures that each identified area is underpinned by actual data. However, both the production bore data and air photo data are spatially incomplete. There are some areas where data are severely lacking. Consequently, we have confidence in those areas we have identified as current risk, but there will be other areas within NSW where there are currently saline outbreaks and shallow watertables

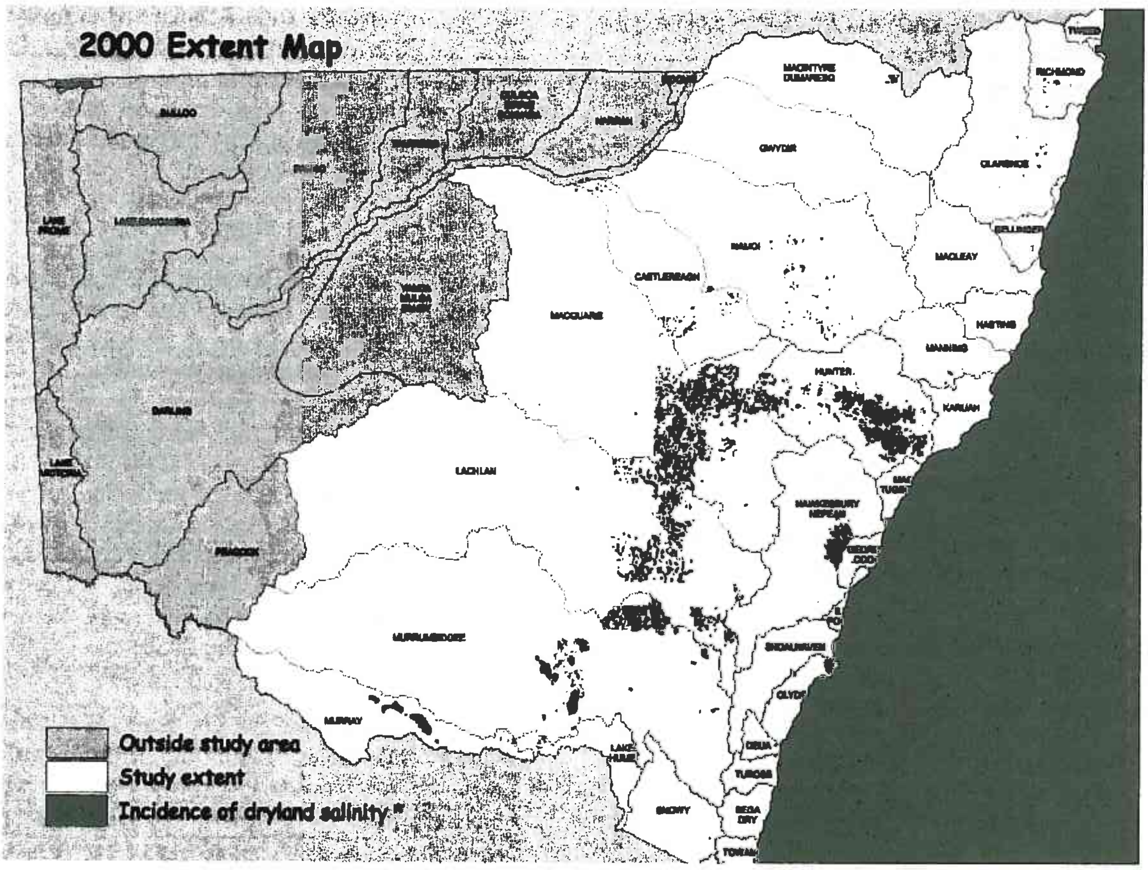

Figure 4. Current extent map of known areas of shallow watertables or salinity outbreaks.

occurring. But since no data set comprehensively covers all areas of NSW, some areas will have been missed in the analyses. Therefore, the results should be viewed as minimum or conservative values.

The strengths of the adopted approach are:

- Each delineated area identified in the analyses is underpinned by measured data; either bore data or from aerial photography;
- no spatial extrapolation to artificially infer other areas of shallow watertables was undertaken;
- depth to watertable, rather than watertable elevation was considered for all bore analyses;
- approach is conservative, in that it only focuses on areas where we have measured data and ignores areas where we have no data; and
- the method reflects the quality and quantity of available data; we did not push the analyses beyond the accuracy of available data.

The limitations of the adopted approach are:

- The extent of dryland salinity and shallow watertables identified is limited by the spatial extent of data available for this project;
- effects of topography were unable to be quantified; and
- there is a potential to produce larger areas of flat watertables in areas where the network of bores with similar depths to watertable is sparse.

3.4 Rates of Groundwater Rise

Average rates of groundwater rise derived from monitored bore data are presented for each catchment considered in the Murray-Darling Basin in Table 2. Higher rates of rise are evident for the southern catchments with rates of rise decreasing for the northern catchments.

Table 2. Average rates of rise across all groundwater flow systems for each catchment considered in the Murray-Darling Basin.

Catchment	Rise (m/yr)
Murray	0.15
Murrumbidgee	0.14
Lachlan	0.11
Macintyre	-0.01
Gwydir	0.04
Namoi	0.06
Castlereagh	0.11
Macquarie	0.09

3.5 Current and Future Extent

Estimated current and future areas are presented on a catchment basis in Table 3.

Table 3. Estimated areas (ha) affected by depth of watertable of less than 2m under current conditions and year 2020 and year 2050 scenarios.

Catchment	Year		
	2000	2020	2050
Lake Hume	127	3 973	19 254
Murray	39 526	168 978	293 191
Murrumbidgee	58 098	286 848	469 500
Lachlan	19 793	38 845	153 264
Macquarie	25 072	36 767	90 848
Castlereagh	1 197	12 005	174 666
Namoi	2 896	4 288	27 837
Gwydir	0*	0*	2 973
Macintyre	3 800	25 500	67 224
Richmond	155	n/a	n/a
Clarence	91	n/a	n/a
Bellinger	27	n/a	n/a
Manning	34	n/a	n/a
Hunter	22 954	n/a	n/a
Hawkesbury	4 806	n/a	n/a
Georges/Cooks	13	n/a	n/a
Deua	11	n/a	n/a
Total	178600	577204	1298757

* zero values for the Gwydir catchment reflect a lack of available data rather than zero risk

In New South Wales, approximately 180 000 ha of land have shallow watertables or are currently affected by dryland salinity. Over 90% of this occurs in five catchments - the Murray, Murrumbidgee, Lachlan, Macquarie and Hunter Rivers. Apart from the Hunter and Hawkesbury/Nepean River catchments there is no measured data indicating extensive areas of existing dryland salinity or shallow groundwater in other coastal catchments of NSW.

Within the Murray-Darling Basin (MDB) alone, the area affected by 2050 is predicted to increase from the current 152 000 hectares to 1.3 million ha, a greater than eight-fold increase. The coastal catchments are not represented in this future prediction due to the paucity of groundwater data on which to make the estimates.

3.6 Current and Future Impacts

A summary of the key assets at risk from dryland salinity is given in Table 4. The largest current and future impacts will be in agricultural areas (cropping and pastoral). Over 90% of land currently affected by salinity is designated agricultural. Agricultural areas affected by dryland salinity could increase eight-fold over the next 50 years. The length of roads and railways affected by salinity is likely to increase five-fold over the next 50 years. Urban salinity, already an issue in many towns in New South Wales, will worsen, with areas affected increasing from the current 954 ha to 3 646 ha by 2050.

Table 4. Summary of the key assets at risk from shallow watertables within the Murray-Darling Basin.

Assets affected	2000	2020	2050
Cropping land (ha)	28 467	114 445	223 658
Forests (ha)	481	15 348	34 507
Horticulture land (ha)	524	1 913	4 780
Pasture land (ha)	112 951	412 125	927 171
Highways (km)	107	331	534
Major roads (km)	86	298	701
Minor roads (km)	603	1 959	3 615
Bridges	12	22	43
Railways (km)	78	226	416
Built-up areas (ha)	954	2 209	3 646

4. OUTCOMES AND CONCLUSIONS

The results presented in this report illustrate the magnitude of the effects of dryland salinity in NSW. Key results showed:

- Approximately 180 000 ha of land have shallow watertables or are currently affected by dryland salinity in New South Wales. Over 90% of these occur in five catchments - the Murray, Murrumbidgee, Lachlan, Macquarie and Hunter Rivers.
- Within the Murray–Darling Basin alone, the area predicted to be at risk will increase from approximately 152 000 ha to 1.3 million hectares by 2050, a greater than eight-fold increase.

- Of the 152 000 ha of land currently at risk from shallow groundwater within the Murray-Darling Basin, 93 per cent is agricultural land. The area of agricultural land within the Murray-Darling Basin affected by shallow watertables will increase from the current 142 000 ha to almost 1.2 million ha by 2050
- It is currently estimated that 954 ha of built-up areas within the Murray–Darling Basin are affected by shallow watertables. This could potentially increase to over 3600 ha by 2050.

Since the results produced only show known areas of dryland salinity and shallow watertables, further work to improve the spatial coverage of current saline outbreak areas and more extensive bore network is required. This should include a review of the current groundwater bore network and other related data sets in NSW.

Improved acquisition and compilation of data from a larger number of monitored bores is recommended to improve estimates of rates of groundwater rise. More detailed groundwater flow systems data could be used to refine the estimated rates of rise.

A major outcome from this study was that existing techniques that relate topography to depth of watertable were inadequate. It is recommended that more complex topographical attributes be assessed as an indicator of shallow watertables to improve current and future extent maps.

The revised current and future extent maps should be used to refine the end of valley salt loads for Murray-Darling Basin Catchments as part of the Murray-Darling Basin Commission Salinity Audit updates.

Results showed the large extent of dryland salinity in the Hunter Catchment. Current work is being finalised to improve current and future predictions of dryland salinity in the Hunter.
A more comprehensive salinity assessment is required through the integration of these results with spatial models of water and salt movement in the landscape and socioeconomic data to provide tools for regional and catchment planning. This work is currently underway within the NSW Department of Land and Water Conservation.

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